DEVELOPMENT AND VALIDATION OF THE UNIVERSAL DESIGN MOBILE INTERFACE GUIDELINES THROUGH A MHEALTH APPLICATION FOR INDIVIDUALS AGING WITH MULTIPLE SCLEROSIS

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I dedicate this dissertation to my loving family.

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LIST OF SYMBOLS AND ABBREVIATIONS

AT	Assistive Technology
CNS	Central nervous system
DfA	Design for Aging
DMDs	Disease-modifying drugs
I	Interface Structure Guidelines
ICT	Information and communication technology
IT	Information Technology
F	Features Guidelines
MID	Handheld Mobile Device Interface Design Guidelines
mHealth	Mobile health
MS	Multiple Sclerosis
MSAA	Multiple Sclerosis Association of America
PPMS	Primary progressive multiple sclerosis
PRMS	Progressive relapsing multiple sclerosis
QOL	Quality of living
RPM	Remote patient monitoring

RRMS	Relapsing-remitting multiple sclerosis
SPMS	Secondary progressive multiple sclerosis
SUS	System Usability Scale
UD	Universal Design
UDMIG	Universal Design Mobile Interface Guidelines
UI	User Interface
UU	Universal Usability
WHO	World Health Organization

SUMMARY

An aging population is growing (Colby & Ortman, 2017). By 2030, one out of five Americans is estimated to be of age 65 and over. As people age, they experience the decline in both health and function (Becker, 2004; Fisk et al., 2009; Holzinger et al., 2007). The majority of seniors have myriad and ranges of functional limitations, such as vision, hearing, motor, cognition, and dexterity, which can impact their use of and interaction with user interfaces. Typical user interface problems include misunderstanding of general icons, long task completion times, poor task performance, errors, difficulty reading text due to small font size and poor color contrast, and confusion associating inputs with outputs (Becker 2004; Bederson et al. 2003; Chadwick-Dias et al. 2003). Regardless of these issues, product and user interface design can help older adults by incorporating their particular sensory-perception, motor, communication, and mental needs into the design of the interfaces (Morell, 2001).

Similar to people who experience normal aging, mobile technologies provide great potential to support people aging *with* disability (Sanford & Gonzalez, 2016). However, there is a dearth of prior research on the needs and abilities of this user population. A large number of people with disabilities acquired in early or middle life are living longer (G. Anderson, 2010; Sheets, 2005). These individuals are experiencing the effects of aging earlier than others (Jette and Field, 2007). Additionally, individuals aging *with* disabilities experience a combination of pre-existing impairments and age-related limitations, which often leads to a newly acquired age-related functional losses, comorbidities, and secondary age-related conditions (Harrington et al., 2015; Jette & Field, 2007). Although younger adults with disabilities may compensate for their impairments through the use of technologies, devices, and techniques, newly developed age-related limitations can reduce the effectiveness of these alternative approaches and reduce the quality of life (QOL) (Jette and Field, 2007). Mobile technology provides great potential to help individuals aging with

disabilities to meet their needs (Agree, 2014). Nevertheless, there is a need for further research to solve the problems with access, usability, and utility to better understand the individualized preferences and support the needs of this unique population. Moreover, this imposes the need for personalized technologies that assist people aging with disabilities to adapt to the challenges of later life and to improve their QOL.

Several design strategies are used to address the usability issues of desktop and mobile interfaces that are relevant for an aging population. Four of the most commonly applied strategies include Universal Design (UD) (Ronald Mace, 1988), Design for Aging (DfA) (Fisk et al., 2009), Universal Usability (UU) (Shneiderman & Plaisant, 2010), and Guidelines for handheld mobile device interface design (MID) (Gong & Tarasewich, 2004). Analysis of the guidelines suggested that none of the four strategies alone were sufficiently comprehensive and inclusive enough to meet the range and diversity of usability needs of older adults including those aging with disabilities within the environment of mobile interfaces.

The purpose of this research project was to develop a comprehensive integrative universal design strategy, the Universal Design Mobile Interface Guidelines (UDMIG) for people aging with and without disabilities. The mobile health (mHealth) self-management holistic application that meets the health and wellness needs of individuals aging with Multiple Sclerosis (MS) and provides personalized and customizable support, MS Assistant, was designed and evaluated. The UDMIG were validated through their application to the design of the mHealth app.

CHAPTER 1. INTRODUCTION

An aging population is growing (Colby & Ortman, 2017). By 2030, one out of five Americans is estimated to be of age 65 and over. As people age, they experience the decline in both health and function (Becker, 2004; Fisk et al., 2009; Holzinger et al., 2007). The majority of seniors have myriad and ranges of functional limitations, such as vision, hearing, motor, cognition, and dexterity, which can impact their use of and interaction with user interfaces. Typical user interface problems include misunderstanding of general icons, long task completion times, poor task performance, errors, difficulty reading text due to small font size and poor color contrast, and confusion associating inputs with outputs (Becker 2004; Bederson et al. 2003; Chadwick-Dias et al. 2003). Regardless of these issues, product and user interface design can help older adults by incorporating their particular sensory-perception, motor, communication, and mental needs into the design of the interfaces (Morell, 2001).

Similar to people who experience normal aging, mobile technologies provide great potential to support people aging *with* disability (Sanford & Gonzalez, 2016). However, there is a dearth of prior research on the needs and abilities of this user population. A large number of people with disabilities acquired in early or middle life are living longer (G. Anderson, 2010; Sheets, 2005). These individuals are experiencing the effects of aging earlier than others (Jette and Field, 2007). Additionally, individuals aging *with* disabilities experience a combination of pre-existing impairments and age-related limitations, which often leads to a newly acquired age-related functional losses, comorbidities, and secondary age-related conditions (Harrington et al., 2015; Jette & Field, 2007). Although younger adults with disabilities may compensate for their impairments through the use of technologies, devices, and techniques, newly developed age-related limitations can reduce the effectiveness of these alternative approaches and reduce the quality of life (QOL) (Jette and Field, 2007). Mobile technology provides great potential to help individuals aging with disabilities to meet their needs (Agree, 2014). Nevertheless, there is a need for further research to solve the problems with access, usability, and utility to better understand the individualized preferences and support the needs of this unique population. Moreover, this imposes the need for personalized technologies that assist people aging with disabilities to adapt to the challenges of later life and to improve their QOL.

Several design strategies are used to address the usability issues of desktop and mobile interfaces that are relevant for an aging population. Four of the most commonly applied strategies include Universal Design (UD) (Ronald Mace, 1988), Design for Aging (DfA) (Fisk et al., 2009), Universal Usability (UU) (Shneiderman & Plaisant, 2010), and Guidelines for handheld mobile device interface design (MID) (Gong & Tarasewich, 2004). Analysis of the guidelines suggested that none of the four strategies alone were sufficiently comprehensive and inclusive enough to meet the range and diversity of usability needs of older adults including those aging with disabilities within the environment of mobile interfaces.

1.1 Purpose, Specific Aims, and Research Questions

The purpose of this research project was to develop a comprehensive integrative universal design strategy, the Universal Design Mobile Interface Guidelines (UDMIG) for people aging with and without disabilities. The mobile health (mHealth) self-management holistic application that meets the health and wellness needs of individuals aging with Multiple Sclerosis (MS) and provides personalized and customizable support, MS Assistant, was designed and evaluated. The UDMIG were validated through their application to the design of the mHealth app.

Specific aims of the project are to:

1. *Develop the UDMIG* to guide the design of mobile interfaces that would be appropriate for an aging population based on the four design strategies by:
    a. Analyzing the four most commonly used design strategies to identify and categorize their similarities and classify their differences, and
    b. Integrating these four strategies into a comprehensive set of guidelines;
2. *Identify the functional* features in mobile applications that meet the needs of individuals aging with MS by;
    a. Identifying the health and wellness needs of people aging with MS;
3. *Refine the* UDMIG to include people aging with disabilities through *the development of the mobile application* that meets the health and wellness self-management needs of people aging with MS by:
    a. Recognizing the design characteristics of the crucial design elements in mobile health (mHealth) user interfaces for people aging with MS, and
    b. Refining the UDMIG to include the population aging with disabilities;
4. *Design and test the effectiveness of MS Assistant* in meeting the health and wellness needs to *validate the UDMIG* through an iterative evaluation of a prototype application designed based on the guidelines by:
    a. Evaluating the usability of MS Assistant through iterative testing: expert review and usability testing with the end-user population, and
    b. Assessing the utility of MS Assistant with the end-users: subjective feedback from end-users.

In this research project, I propose the following thesis statement: *Integrative and comprehensive design guidelines, informed by the existing strategies and user needs, will* *help with the design of the future mHealth applications that would be usable to a population aging with disabilities.*

In order to prove this thesis statement, I developed the comprehensive design guidelines for the mobile applications for an aging population, including those aging with disabilities. In addition, I identified the health and wellness self-management needs in people aging with MS and the functional features in mobile apps that meet those needs. Moreover, I recognized the design characteristics of the important design elements in mHealth user interfaces for the same population of users. Based on the results of the two formative studies and the UDMIG, I developed a holistic mHealth application that helps the individuals aging with MS self-manage their health and wellness and offers individualized and personalized support. Finally, I tested the effectiveness of MS Assistant in meeting the health and wellness needs and validated the UDMIG through an iterative evaluation of the usability and the utility of a prototype application.

1.1.1 Specific Aim 1: Development of the UDMIG

Research Question 1. What are the strengths and limitations of the design strategies commonly used to guide the development of mHealth applications for older adults? A small number of design strategies have been developed to guide the design of the products and user interfaces for an aging population. Additionally, universal strategies for the user interfaces are usually applied when designing for this end-user population. I described, analyzed, and compared UD with the other three commonly used design strategies for user interfaces in the aging population (DfA, UU, MID). The results of this review led to the integration of those strategies with UD into the comprehensive set of guidelines, the UDMIG.

1.1.2 Specific Aim 2: Identification of the functional features in mobile applications that meet the needs of individuals aging with MS

Research Question 2. What are the health and wellness self-management needs among people aging with MS and related functional features in mobile applications that meet those needs? Understanding of the condition self-management from the end-users' standpoint is a fundamental aspect of mHealth application design process. For the purpose of understanding and defining the functionality of the mobile application, I conducted focus groups where individuals diagnosed with MS at least five years ago discussed their health and wellness needs. The qualitative study resulted in the recommendations for the design of MS-specific mHealth applications.

1.1.3 Specific Aim 3: Refinement of the UDMIG to include people aging with disabilities through the development of the mobile application that meets the health and wellness self-management needs of people aging with MS

Research Question 3. What are the design characteristics of the important design elements in mHealth user interfaces for people aging with MS? Usability of mobile interfaces is an essential and critical aspect of the design. There is a dearth of literature on this topic for people aging with MS. For the purpose of understanding the usability of the mHealth application, I conducted usability testing that identified barriers and facilitators to the usability of salient design elements in current mHealth applications. The formative study resulted in the set of the design recommendations to improve user interfaces for individuals aging with MS. These recommendations informed the UDMIG by highlighting the design elements and its characteristics that are crucial for a population of people aging with disability.

1.1.4 Specific Aim 4: Design and testing of the effectiveness of the mHealth app in meeting the health and wellness needs of end-users to validate the UDMIG

Research Question 4. What is the effectiveness of the design features in MS Assistant designed based on the UDMIG, in meeting the usability needs of individuals aging with MS? I designed and developed the self-management mHealth application, MS Assistant, to validate the UDMIG. Two iterative evaluation studies were conducted to validate the UDMIG. These studies reported that the UDMIG applied to the design of MS Assistant meet the usability requirements of individuals aging with MS.

Research Question 5. What is the effectiveness of the functional features in MS Assistant in meeting the health and wellness needs of people aging with MS?

MS Assistant was designed to meet the health needs of individuals aging with MS based on the recommendations and design implications of the needs assessment formative study. The utility evaluation of MS Assistant with the end-user population confirmed that the mobile app and its functional features meet their health and wellness self-management needs.

1.2 Research Design

In this research project, I have conducted two formative studies to understand the needs of individuals aging with MS, which informed the functionality and usability of the mHealth application, MS Assistant, and the UDMIG to include population aging with disabilities. I iteratively tested the comprehensive guidelines and MS Assistant through an expert review and usability testing with the end-user population to validate the UDMIG and prove usability and usefulness of the condition self-management app. Research plan summary with the research questions, outcome measures, related research methods and instruments is presented in Table 1.

Table 1 – Research plan summary

Research Questions	Methods	Outcome Measures	Research Instruments
RQ1	• A systematic review of the design guidelines	• The strengths and limitations of the four strategies for designing interactive mobile interfaces for older adults	• P-E Fit Model
RQ2	• A systematic review the functional features, • Focus groups	• The needs for self-management of health and wellness • The functional features in mHealth self-management applications that meet those needs	• App search; A set of important functional features in mHealth apps; Manual assessment of the identified and new features • Focus group discussion
RQ3	• Usability testing, • Semi-structured interviews	• Completion rates; Number and frequency of help requests; Types of unique help requests (barriers); Ratings of design elements; • The barriers and facilitators to usability and related design recommendations	• Analysis of the video transcripts; Design elements ratings (Likert scale 1-5) • Interview questions related to design elements (barriers and facilitators)
RQ4	• Expert review, • Usability testing	• Ratings of the design features based on the UDMIG v.2.1 design criteria; Usability problems and related design recommendations. • Ratings of the design features based on the UDMIG v.2.1 design criteria; Completion rates; Number and types of errors; Number and types of help requests; System Usability Scale (SUS) score.	• UDMIG v.2.1 design criteria questionnaire ratings (Likert scale of 1-5); Analysis of audio transcripts. • UDMIG v.2.1 design criteria questionnaire ratings (Likert scale of 1-5); Analysis of video transcripts; SUS.
RQ5	• Utility evaluation	• Usefulness and importance ratings of the functional features	• Usefulness and importance ratings (Likert scale of 1-5)

User-Centered Design (UCD) methods, such as focus groups, usability testing, semi-structured interviews, and expert review, were used to identify user needs, specify the barriers and facilitators to usability, and iteratively test the UDMIG to support generalization into universal guidelines.

Focus groups were used as a widely used self-contained research method for gathering qualitative data (Kitzinger, 1994; Morgan, 1996a, 1996b). This research method is singular in focus, benefits from the group interactions to generate more in-depth information, and is characterized by its humanistic nature of research (D. W. Stewart & Shamdasani, 2014). It was used for the purpose of the qualitative study with individuals with MS as well as those aging with the condition, to: 1) understand their health and wellness needs for self-management, and 2) recognize the opportunities to meet those needs through mobile technologies and specific functional features. A systematic review of the functional features in MS-specific mobile applications is presented with the purpose to understand the current state of mobile application utility and to identify two apps with the most versatile functionality.

Usability testing was used with the purpose to collect empirical data while observing representative end users using the consumer mHealth applications to perform realistic tasks (Rubin & Chisnell, 2008). This UCD method was chosen as a reliable indicator of potential usability problems and the means to solve them (Rubin & Chisnell, 2008). Additionally, a semi-structured interview was conducted as a qualitative method to explore the responses to open-ended questions further in order to understand what works (i.e., facilitators to usability) and to identify the problems that I may not have been considered (i.e., barriers to usability) (Galletta, 2013). I used mixed-methods design to complement the results of the usability study with the results of semi-structured interviews and to further enhance, elaborate, and clarify those results (Greene, Caracelli, & Graham, 1989). In this study, the purpose of the usability testing was to identify important design elements and their characteristics in mHealth apps for the target population. Semi-structured interviews were used to further extract more data about the barriers and facilitators to usability.

The strength of the expert review is that it is time-efficient in identifying the elementary and tactical problems that can be quickly addressed to improve the mobile interface (Six, 2009). This method is useful in rating the design against the guidelines and design criteria. However, usability testing that results in the perspectives of users is necessary to extract more in-depth data (Rubin & Chisnell, 2008). Experts are not familiar with the specific context of use as end-users are (Six, 2009). Therefore, they explore the surface of the problems. Overall, the combination of the expert review and usability testing (or interviews) with target subjects brings a greater range of results and ensures content validity (Naar-King, Ellis, Frey, & Ondersma, 2003; Six, 2009). In this study, I used mixed-methods design to inform the usability testing by using the results from the expert reviews (Greene et al., 1989). Specifically, expert review results were used to inform the UDMIG v.2.1 and the design of MS Assistant, which was further tested with its target population. The purpose of both studies that tested MS Assistant was the evaluation and validation of the UDMIG v.2.1 through its application to the mHealth app. Additionally, usability testing evaluated its utility and the functionality of its features with the purpose to confirm and further clarify the needs of people with MS for self-management of their health and wellness.

Figure 1 presents the process diagram, which illustrates all the design stages of this research study that helped design and evaluate the UDMIG and the mHealth application for individuals aging with MS.

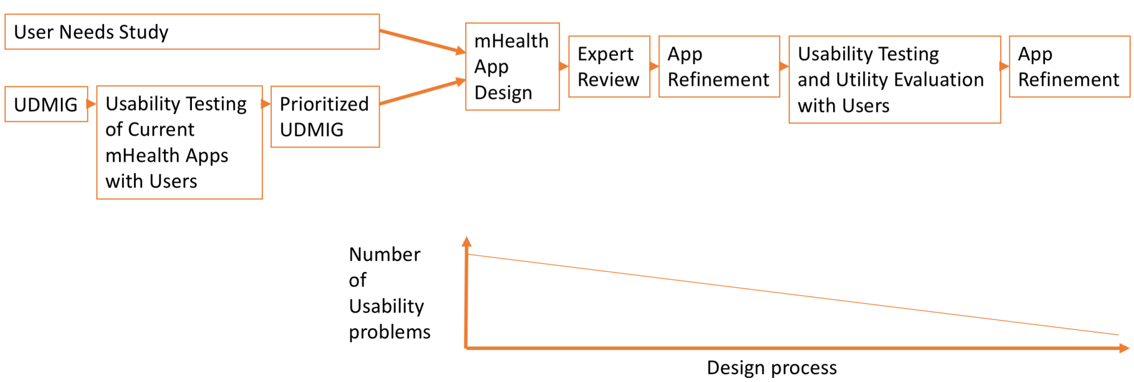


Figure 1 – Process diagram

1.3 Contributions

This project resulted in the following contributions:

1. The validated UDMIG that integrate UD with the commonly used design strategies to guide and enhance the usability of mobile interfaces for an aging population, including individuals aging with disabilities (Chapters 2, 3, and 5);

2. The design recommendations for developing the mHealth technologies for people aging with MS from the end-users' perspective that meet their health and wellness needs (Chapter 3);
3. Usability recommendations for the development of mobile user interfaces for a population aging with disabilities (Chapter 3);
4. The design and evaluation of the evidence-based app MS Assistant: a novel mHealth application that provides a personalized and customizable interface within a holistic system for self-management of the condition (Chapters 3 and 4);
5. Conducted and proposed process for designing mHealth applications (Chapter 6).

The following three chapters will each focus on a specific aim. In chapter 5, I summarize my findings and reflect on my research.

CHAPTER 2. DEVELOPMENT OF THE UNIVERSAL DESIGN MOBILE INTERFACE GUIDELINES

The purpose of this chapter is to address specific aim 1 and to answer Research Question 1: *What are the strengths and limitations of the design strategies commonly used to guide the development of mHealth applications for older adults?* To answer Research Question 1, I describe the theoretical approach for my study through the analysis and comparison of UD and three design strategies commonly used for the design of the mobile interfaces for an aging population. I then present the development process of the UDMIG for an aging population from their initial and simplistic version, UDMIG v.1.0 (Ruzic Kascak, Liu, & Sanford, 2015; Ruzic Kascak, Rebola, & Sanford, 2014), to the integrated and refined one, UDMIG v.2.0 (Ruzic & Sanford, 2017).

2.1 Theoretical Approach

Technology use among the aging population is growing and becoming more widespread (Fisk, Rogers, Charness, Czaja, & Sharit, 2009). However, with increased age, many individuals experience decreased ranges and levels of abilities, such as vision, hearing, haptics, cognition, and dexterity, which can negatively impact their use of and interaction with user interfaces. Typical user interface problems include misunderstanding of general icons, long task completion times, poor task performance, errors, difficulty reading text due to small font size and poor color contrast, and confusion associating inputs with outputs (Becker, 2004; Bederson, Lee, Sherman, Herrnson, & Niemi, 2003; Chadwick-Dias, McNulty, & Tullis, 2003). Despite these issues, user interface design can help older adults by incorporating their particular needs into the design of the mobile applications (Morrell, 2001). Similarly, mobile technologies provide great potential to support people aging *with* disability (Sanford & Gonzalez, 2016). However, there is a scarcity of prior research on the needs and abilities of this user population.

Various design strategies are often used to address usability issues of desktop and mobile interfaces that are relevant for an aging population and individuals with functional limitations. UD (Ronald Mace, 1988) is the design of everyday products that are usable by everyone (to the greatest extent possible). By doing so, UD facilitates usability, thereby eliminating physical barriers to usability (and inclusivity) that would be experienced by any individual, including older adults and people with disabilities (Law, Yi, Choi, & Jacko, 2008; Sanford, 2012). The design strategy was originally developed to apply to physical products and environments (Sanford, 2012). Therefore, the Principles of UD need to be updated and refined to be applicable to the design of digital technologies and to meet the needs of the individuals with the wide range of abilities in a mobile environment. An additional three design strategies most commonly applied to user interfaces for an aging population and individuals with disabilities include DfA, UU, and MID.

In contrast to UD, DfA (Fisk et al., 2009) specifically addresses the particular functional limitations associated with aging and user interfaces. DfA identifies the factors that constrain the use of products and user interfaces by older adults, as well as aspects of human-computer interface design that accommodate older users with age-associated disabilities and limitations (Zajicek, 2001). It has fifty-two design guidelines grouped into six categories that cover design of visual, auditory, and haptic presentation of information, input and output devices, and effective interface design. UU is comprised of eight guidelines, called the Eight Golden Rules of Interface Design. Whereas UD was initially developed for the design of physical environments (e.g., buildings, spaces, products, graphics), UU is intended to support usability, inclusivity, and utility of information and communication technologies (Shneiderman & Plaisant, 2010). Based on UU, MID (Gong & Tarasewich, 2004) modified and extended the eight golden rules to provide general design guidance for the usability of mobile platforms (Table 2).

The four sets of existing guidelines were analyzed to determine their applicability to the design of mobile health and wellness interfaces for older adults. Analysis of the guidelines suggested that none of the four strategies alone were sufficiently comprehensive and inclusive enough to meet the range and diversity of usability needs of older adults within the environment of mobile interfaces. To address these usability needs and reconcile inconsistencies among the four strategies, an initial set of integrative holistic guidelines, UDMIG, was proposed to ensure usability of mobile applications by older adults. The UDMIG were a result of the incorporation of the three strategies with UD to improve and help inform this comprehensive theoretical framework. This chapter reports the first simplistic version of the guidelines (Kascak et al., 2014; Kascak Ruzic, Lee, Liu, & Sanford, 2015) and a continued development, refinement, and extension of those guidelines into UDMIG v.2.0 (Ruzic & Sanford, 2016), and later into UDMIG v.2.1 (Ruzic, Lee, Liu, & Sanford, 2016), which is a more robust and inclusive set of design guidelines.

Table 2 – Four strategies' specific domains and types of users

Strategies	**Specific Domains**	**Types of Users**	**Reference**
Universal Design	Physical environments	All users	(Ronald Mace, 1988)
Design for Aging	Technology systems and products, environments, work tasks, and training and instructional programs	Older adults	(Fisk et al., 2009)
Universal Usability	ICT	All users	(Shneiderman, 1986)
Guidelines for handheld mobile device interface design	Mobile interfaces	All users	(Gong & Tarasewich, 2004)

2.1.1 Universal Design

Universal Design was defined by Mace (1988) as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design." The purpose of UD is the design of usable and equitable environments and products by reducing their complexity and minimizing individuals' dependence on their physical and cognitive abilities when interacting with them (Imrie, 2012; Tobias, 2003). Burgstahler (Ron Mace, 1997) explained its inclusivity as it applies to the users' characteristics:

> "When UD principles are applied, products and environments meet the needs of potential users with a wide variety of characteristics. Disability is just one of many characteristics that an individual might possess."

UD is an integral component of everyday design, considering users' ranges and combinations of abilities from the beginning of the design process (Ruptash, 2013; Sanford, 2012). As a result, UD creates environments and products that any person, regardless of cognitive and physical impairments, can use and access. It advocates for usable design by the greatest number of people, addressing a wider range of limitations and combinations of limitations that one might have ("Falls Among Older Adults: An Overview," 2013). To promulgate UD, seven principles and thirty associated design guidelines were developed by a team of designers at NC State University (Connell et al., 1997) (Table 3).

Table 3 – The Principles of Universal Design©

Principle One: Equitable Use
The design is useful and marketable to people with diverse abilities
1a. Provide the same means of use for all users: identical whenever possible; equivalent when not
1b. Avoid segregating or stigmatizing any users
1c. Provisions for privacy, security, and safety should be equally available to all users
1d. Make the design appealing to all users
Principle Two: Flexibility in Use
The design accommodates a wide range of individual preferences and abilities
2a. Provide choice in methods of use
2b. Accommodate right- or left-handed access and use
2c. Facilitate the user's accuracy and precision
2d. Provide adaptability to the user's pace
Principle Three: Simple and Intuitive Use
Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level
3a. Eliminate unnecessary complexity
3b. Be consistent with user expectations and intuition
3c. Accommodate a wide range of literacy and language skills
3d. Arrange information consistent with its importance
3e. Provide effective prompting and feedback during and after task completion
Principle Four: Perceptible Information
The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities
4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information
4b. Provide adequate contrast between essential information and its surroundings
4c. Maximize "legibility" of essential information
4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions)
4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations
Principle Five: Tolerance for Error
The design minimizes hazards and the adverse consequences of accidental or unintended actions
5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded
5b. Provide warnings of hazards and errors
5c. Provide fail safe features
5d. Discourage unconscious action in tasks that require vigilance
Principle Six: Low Physical Effort
The design can be used efficiently and comfortably and with a minimum of fatigue
6a. Allow user to maintain a neutral body position
6b. Use reasonable operating forces
6c. Minimize repetitive actions
6d. Minimize sustained physical effort
Principle Seven: Size and Space for Approach and Use
Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility
7a. Provide a clear line of sight to important elements for any seated or standing user
7b. Make reach to all components comfortable for any seated or standing user
7c. Accommodate variations in hand and grip size
7d. Provide adequate space for the use of assistive devices or personal assistance

Source: Connell et al., 1997. The Principles of Universal Design

2.1.2 *Design for Aging*

DfA is a tool that not only articulates the problems that must be considered when designing systems, products, and environments for older adults but also provides design guidelines for addressing those problems (Fisk et al., 2009).

Table 4 – Design for Aging categories

1. *Guidelines for visual presentation of information* secure required visual information for aging population, focusing on adequate levels of illumination and improved conditions for visual perception, increasing sizes, brightness, and contrast of visual objects (e.g., text, images, icons), isolating messages from other message channels, keeping consistent positioning of target items, and engaging alternative sensory systems for users who have serious visual impairments
2. *Guidelines for auditory presentation of information* help ensure that older adults receive needed auditory information, with focus on making speech more intelligible, on avoiding compressed and speeded speech, on using context to interpret speech (e.g., good structure in written and spoken texts, videoconferencing), on using other sensory modalities, and on improving the efficacy of warning signals
3. *Guidelines for haptic presentation of information* assist with increasing the quality of interaction with technology user interfaces while using the haptic processing and concentrating on the use of vibration to signal events and a choice of vibration frequency
4. *Guidelines for the design of input devices* help with user interaction with input devices by minimizing the number of steps of the process as well as the number of controls, providing the consistency of the layout control elements, designing for expectations or affordances (visual elements that suggest function), and providing alternative ways to navigate with input devices
5. *Guidelines for the design of output devices* focus on specific issues related to devices and to visual and auditory displays, such as choosing the type of display and the angle from which the display is read, shielding displays in outdoor environments, effectively presenting the important and warning information, and providing the tactile output devices for simple signaling
6. *Guidelines for effective interface design* address the human-computer interface problems related to menu designs, display layouts, system navigation, information organization, error recovery, compatibility, and design of help systems to accommodate older adults' expectations about how the system works and to ensure their goals match how the system functions

Source: (Fisk et al., 2009)

DfA consists of the 52 design guidelines, grouped into 6 categories (Table 4) that cover the factors that constrain the use of user interfaces by older adults, as well as aspects of human-computer interface design that accommodate older users with age-associated disabilities and limitations (i.e., memory, cognitive, hearing, visual, dexterity, and physical impairments) (Zajicek, 2001).

2.1.3 Universal Usability

To extend the notion of universal design beyond the physical environment and make it applicable to information and communication technology (ICT), UU was developed to make ICT interfaces usable and accessible by all people, with and without disabilities (Meiselwitz, Wentz, & Lazar, 2010). Shneiderman (2000) believed that UU would be pervasive, enabling more than 90% of all households to be successful users of information and communications services at least once a week.

Table 5 – Eight Golden Rules of Interface Design

1. *Strive for consistency* Consistent sequences of actions are required in similar situations and identical terminology should be used whenever possible
2. *Cater to universal usability* The needs of diverse users including novices, experts, users of all age ranges, and users with disabilities need to be recognized
3. *Offer informative feedback* For frequent and minor user actions, there should be modest system feedback, whereas for infrequent and major actions, the response should be more substantial
4. *Design dialog to yield closure* Sequences of actions should be organized into groups with a beginning, middle, and end, with an informative feedback at the completion of a group of actions
5. *Prevent errors* The system should be designed such that users cannot make serious errors, and if a user makes an error, the interface should detect the error and offer simple, constructive, and specific instructions for recovery
6. *Permit easy reversal of actions* As much as possible, actions should be reversible
7. *Support internal locus of control* Experienced users need to feel they are in charge of the interface and that the interface responds to their actions
8. *Reduce short-term memory load* Interfaces in which users must remember information from one screen and then use that information on another screen should be avoided

Source: (Shneiderman & Plaisant, 2010)

To promote UU, Shneiderman and colleagues developed the *Eight Golden Rules of Interface Design* (Table 5) applicable to most interactive systems to enable the widest range of users to benefit from information and communication services (Shneiderman & Plaisant, 1987).

2.1.4 Handheld Mobile Device Interface Design Guidelines

To accommodate the growing number of mobile devices, the MID guidelines were developed by Gong and Tarasewich (2004) based on the Eight Golden Rules of Interface Design. Among the fifteen design guidelines (Table 6), the first four mirror rules 1, 3, 4 and 7 of the Eight Golden Rules of UU, while the other four are modified versions of the remaining four Golden Rules to fit the mobile environment. The additional seven guidelines address the unique characteristics of the mobile interface environment.

2.1.5 Comparison of the Four Design Strategies

While each of the four design strategies is commonly used to guide the design of desktop and mobile interfaces, none are sufficiently comprehensive to ensure that mobile user interfaces will be usable by older adults. The first three strategies, UD, DfA, and UU, which were developed prior to the proliferation of mobile interfaces, are not specific to this platform. In contrast, whereas the MID is the mobile platform-specific, DfA is the only population-specific (i.e., a focus on older adults) strategy. Moreover, it is also the only strategy that links individuals' needs and abilities to design solutions. As such, it provides both an understanding of *what* the functional problems of older adults are and guidance on *how* design can be used to solve those issues. This person-environment (P-E) fit approach (Lawton & Nahemow, 1973) not only provides an understanding of *why* interface design needs to be different to be usable by older adults but also the tools to create unique and innovative interfaces without relying on a rigid set of prescriptive rules.

Table 6 – Guidelines for Handheld Mobile Device Interface Design

1. *Enable Frequent Users to Use Shortcuts* Reduce the number of operations needed to perform regular (i.e., repetitive) tasks because time is often more critical to a mobile device user
2. *Offer Informative Feedback* For every operator action, provide substantial and understandable system feedback
3. *Design Dialogs to Yield Closure* Organize sequences of actions into groups with a beginning, middle, and end, with an informative feedback at the completion of a group of actions
4. *Support Internal Locus of Control* Provide the interface that responds to user's actions, so that they feel in charge of the system
5. *Consistency* Provide the same "look and feel" (i.e., elements of mobile interfaces) across multiple platforms and devices, and device independent input/output methodologies
6. *Reversal of actions* Ensure that mobile applications rely on network connectivity as little as possible
7. *Error prevention and simple error handling* Ensure that nothing potentially harmful is triggered by too simple an operation (e.g., power on/off)
8. *Reduce short-term memory load* Provide interface that relies on recognition of function choices instead of memorization of commands, and uses different modalities (e.g., sound) to convey information where appropriate
9. *Design for multiple and dynamic contexts* Configure the output to users' needs and preferences (e.g., text size, brightness), allow single- and no-handed operation, and ensure that the application adapts itself automatically to the user's current environment
10. *Design for small devices* Provide word selection instead of requiring text input
11. *Design for limited and split attention* Provide sound and tactile output options
12. *Design for speed and recovery* Stop, start, and resume an application with little or no effort
13. *Design for "top-down" interaction* Present high levels of information and let users decide whether or not to retrieve details
14. *Allow for personalization* Provide users the ability to change settings to their needs or liking
15. *Design for enjoyment* Design visually pleasing and fun as well as usable interfaces

Source: (Gong & Tarasewich, 2004)

In contrast to DfA, the other three design strategies address the design for all users, including those with and without functional limitations. As such, these strategies propose a universal usability approach to everyday design. In addition, all three focus solely on how to design, without linking the design to individuals' needs and abilities. Therefore, while these guidelines may instill a sense of what to design for universal usability, without an understanding of why, it is challenging to develop designs that will achieve that goal.

Among all four strategies, UD is the only one that does not focus on interface design, having been developed primarily for the physical environment. As a result, adaptation and addition of some of the guidelines would be necessary to accommodate the design of the interactive mobile environment. UU originally focused on access for users with disabilities. However, over time, it was expanded to include older and younger adults, users with slow network connections, small screens, no screens, and other limiting technologies (Shneiderman, 2003). Of greater relevance here, UU was initially developed for desktop applications, not for mobile interfaces. Therefore, like UD, UU only partially supports mobile interface design and would require an adaptation to provide full guidance for mobile applications. Finally, while the MID guidelines are an adaptation and extension of some of the UU guidelines for mobile and touchscreen interfaces, these guidelines fall short of accommodating the multiple and combinations of limitations experienced by an aging population.

2.2 Universal Design Mobile Interface Guidelines for an Aging Population

I developed the initial set of inclusive design guidelines, which has been previously reported (L. Kascak, Rébola, & Sanford, 2014; Ruzic Kascak et al., 2015), by applying UU, DfA, and MID (L. Kascak, C. B. Rebola, R. Braunstein, & J. Sanford, 2013a; L. Kascak, C. B. Rebola, R. Braunstein, & J. A. Sanford, 2013b; L. Kascak, Rébola, Braunstein, & Sanford, 2013) to UD principles and guidelines applicable to user interface design (Appendix A).

Dynamic nature of mobile interfaces led to the slight modifications of the existing UD guideline (2a: provide a choice in methods in use to allow users to feel they are in control), and an addition of the two design guidelines specific to mobile environments (3f: Design dialogs to yield closure, 4f: Design for multiple and dynamic contexts) to the existing guidelines. Four UD guidelines are not applicable to the mobile interfaces, and, thus, were taken out of the list.

The first version relied too much on the principles and guidelines of UD as the underlying basis for the UDMIG. As such, it failed to incorporate P-E interaction approach that was a unique contribution of DfA, contained inconsistent language and level of specificity, and needed further refinement.

2.2.1 UDMIG v.2.0

To overcome the problems with UDMIG v.1.0, I developed UDMIG v.2.0 (Ruzic & Sanford, 2017) within a framework based on the P-E fit model (Lawton & Nahemow, 1973) as an organizing principle (Figure 2).

2.2.1.1 <u>Methods</u>

2.2.1.1.1 The Person-Environment Fit Model

The P-E Fit Model (Lawton & Nahemow, 1973) defined and assessed the match or fit between a person's ability and the demands of the environment to promote healthy aging. Usability of mobile applications is achieved when there is a match between a person's ability and the design of the interface (Iwarsson, 2005). In UDMIG v.2.0, the fit between the range of human abilities and the environment is manifested as a set of performance guidelines. These guidelines cover both the contextual environment of the interface and the physical environment in which the interface is used. For purposes of designing interfaces only guidelines specific to the interface environment, itself, were considered in the development of the UDMIG. Moreover, the interface environment can be further differentiated by those guidelines that address the design of the interface structure (e.g., layout and navigation), as well as those that guide the design of the specific design elements (e.g., buttons and text) (Figure 2).

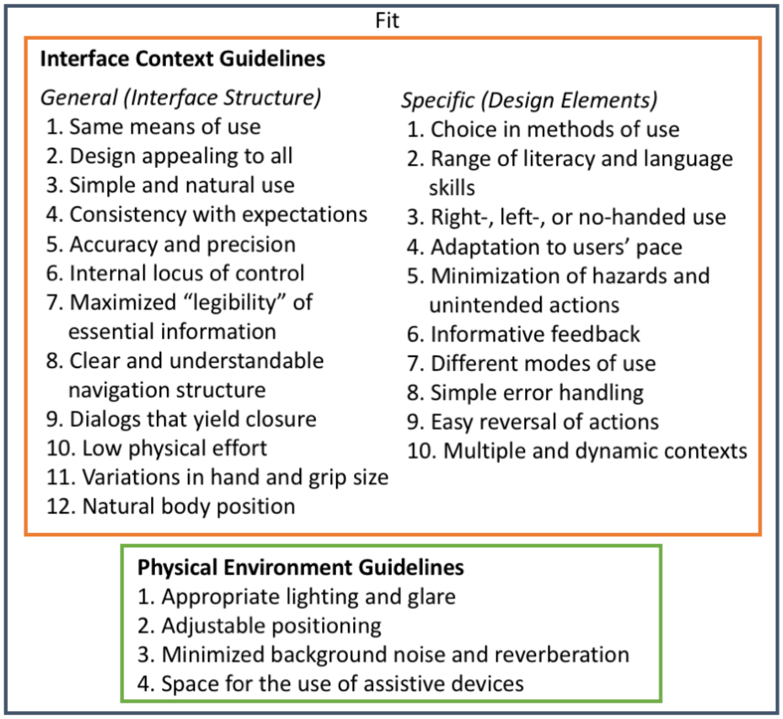


Figure 2 – Structure of UDMIG v.2.0 based on P-E Model and its person, environment, and fit components

2.2.1.1.2 Guideline Categorization

Guidelines were also categorized into prescriptive- vs. performance-based to better organize the four strategies and resulting UDMIG. Whereas the objective of both prescriptive and performance guidelines is to achieve usable design outcomes, they do so in very different ways. Prescriptive guidelines focus on means and methods of achieving usability. They do so by dictating what must be done to achieve a usable outcome, without necessarily indicating what that outcome might look like. As a result, the more prescriptive guidelines are, the fewer design alternatives there are and therefore fewer ways to achieve a usable outcome. In contrast, performance guidelines focus on the product or results of the design process. Performance guidelines typically suggest what the usable outcome should be without regard to how that outcome is achieved. As a result, performance-based guidelines allow greater flexibility in design outcomes by providing opportunities for designers to rely on their interpretation and creativity to achieve a usable outcome. Among the four design strategies, only DfA included prescriptive guidelines (Table 7 and 8).

Table 7 – Design guidelines from the four strategies with resulting UDMIG v.2.0

Data						**Results**	
Prescriptive Guidelines	**Prescriptive/ Performance Guidelines**	**Performance Guidelines**					
DfA			**MID**	**UU**	**UD**	**UDMIG**	
DFA2.1.2 Frequency > 4000Hz DFA2.1.3 Warning signals DFA2.2.4 Longer duration sounds DFA3.1.1 Haptic processing DFA Auditory warnings	DFA2.1.1. Sound volumes; instructions DFA3.1.2 Upper to lower body sites-vibration DFA4.1.5 Speech recognition control DFA4.1.8 Tactile and auditory feedback DFA4.2.7 Built-in controls DFA4.2.9 Warning message DFA4.2.10 Tactile output devices DFA5.4.4 Feedback	DFA2.1.4 Redundant information DFA4.1.1 Default values or profiles DFA4.2.8 Adjustable output sound intensity DFA5.1.2 Adaptability DFA5.1.3 Temporal constraints DFA5.1.4 Characters and targets DFA5.3.3 Frequent important actions DFA5.4.5 Error correction, recovery	MD1. Shortcuts MD2. Feedback MD6. Reversal of actions MD7. Error prevention, handling MD9. Multiple dynamic contexts MD10. Small devices MD11. Limited and split attention MD12. Speed and recovery MD14. Personalization	UU3. Informative feedback UU5. Error handling UU6. Reversal of actions	UD2a. Choice in methods of use UD2b. Right- or left-handed access/use UD2d. Adaptable pace UD3c. Range of literacy/language skills UD3e. Prompting and feedback UD4a. Different modes UD5a. Hazards and errors UD5b. Warnings of hazards/errors UD5c. Fail-safe features UD5d. Unconscious action	F1. Choice in methods of use F2. Range of literacy and language skills F3. Right-, left- or no-handed use F4. Adaptation to user's pace F5. Minimization of hazards and unintended actions F6. Informative feedback F7. Different modes of use F8. Simple error handling F9. Easy reversal of actions F10. Multiple and dynamic contexts	Fit (Per Fit (Person-Environment Interaction) - F
DFA1.2.1Font size DFA1.2.3 Font type DFA1.2.4 50:1 contrast DFA1.3.1 3D and VR displays DFA2.2.2 Speech rates DFA4.2.2 Size of the text	DFA1.2.2 Style sheets DFA2.1.1. Sound volumes; instructions DFA2.2.3 Voice characteristics- DFA4.1.2 Avoid double-clicking DFA4.1.5 Speech recognition control DFA4.2.5 Instructions on resolution DFA4.2.6 Resolution DFA5.2.3 Search history DFA5.2.5 Navigation assistance DFA5.4.1 Standardized format DFA5.4.3 Current system status DFA5.4.4 Feedback situation DFA5.2.2 Site map	DFA1.2.5 Color discriminations DFA1.2.6, DFA5.2.1 Scrolling DFA2.1.5 Background noise and reverberation DFA2.2.1 Pauses in speech DFA4.1.7 Large keypad keys DFA4.2.1 Contrast DFA5.1.1 Clutter DFA5.1.4 Characters and targets DFA5.2.4 Where the user is DFA5.3.1 Information organization DFA5.3.2 Menu structure DFA5.3.3 Frequent important actions DFA5.4.2 Compatibility DFA5.4.6 System tools DFA5.4.7 User levels	MD3. Dialogs to yield closure MD4. Locus of control MD5. Consistency (platforms) MD8. Short-term memory load MD10. Small devices MD13. "Top-down" interaction MD14. Personalization MD4. Locus of control MD15. Enjoyment	UU1. Consistency UU4. Dialogs to yield closure UU7. Locus of control UU8. Short-term memory load	UD1a. Same means of use UD1b. Segregating/stigmatizing users UD1c. Privacy, security, and safety available to all UD1d. Appealing design UD2c. Accuracy and precision UD3a. Eliminate complexity UD3b. Consistency UD3d. Information consistent with importance UD4b. Contrast UD4c. "Legibility" of information UD4d. Differentiate elements UD4e. Compatibility with techniques/devices UD6a. Neutral body position UD6b. Operating forces UD6c. Repetitive actions UD6d. Sustained physical effort UD7c. Variations in hand/grip size	e1. Same means of use e2. Design appealing to all e3. Simple and natural use e4. Consistency with expectations and intuition e5. Accuracy and precision e6. Internal locus of control e7. Maximized "legibility" of essential information e8. Clear and understandable navigation structure e9. Dialogs that yield closure e10. Low physical effort e11. Variations in hand and grip size e12. Natural body position	Micro Environment - e
	DFA1.1.2 Non-reflectant materials DFA1.1.2 Adj. light sources DFA4.2.3 Glare DFA4.2.4 Adj. display	DFA1.1.1 Illumination DFA2.1.5 Background noise/reverberation DFA4.1.10 "Homing"			UD7a. Clear line of sight UD7b. Reach to components UD7d. Space for assistive devices	E1. Appropriate lighting and glare E2. Adjustable positioning E3. Minimized background noise and reverberation E4. Space for use of assistive devices	Macro Environment- E

Table 8 – UDMIG v.2.0 performance-prescriptive guideline

Prescriptive Design Guidelines	**Prescriptive/ Performance**	**Performance Design Guidelines**					
DfA			**MID**	**UU**	**UD**	**UDMIG**	
DFA2.1.2 (F6) DFA2.1.3 (F8) DFA2.2.2 (F4) DFA2.2.4 (F10) DFA3.1.1 (F7) DFA4.2.11 (F8)	DFA2.1.1 (F1) DFA3.1.2 (F7) DFA4.1.5 (F7) DFA4.1.8 (F7) DFA4.2.7 (F10) DFA4.2.9 (F6,F8) DFA4.2.10 (F7) DFA5.2.3 (F10) DFA5.4.4 (F6)	DFA2.1.4 (F7) DFA4.1.1 (F10) DFA4.2.8 (F10) DFA5.1.1 (F6) DFA5.1.2 (F10) DFA5.1.4 (F4) DFA5.3.3 (F5) DFA5.4.2 (F2) DFA5.4.5 (F5) DFA5.4.6 (F4)	MD1. (F4) MD2. (F6) MD7. (F5,F8) MD9. (F10) MD10. (F1,F7) MD11.(F1,F3, F7) MD12. (F4) MD14.(F1,F2, F4,F10)	UU3. (F6) UU5.(F5,F8,F9) UU6. (F9) UU7. (F1)	UD2a. (F1) UD2b. (F3) UD2d. (F4) UD3c. (F2) UD3e. (F6) UD4a. (F7) UD5a. (F5) UD5b. (F8) UD5c. (F9) UD5d. (F5)	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10	Fit - F
DFA1.2.1 (e7) DFA1.2.3 (e7) DFA1.2.4(e5, e7) DFA1.3.1 (e5) DFA4.2.2 (e7)	DFA1.2.2 (e5) DFA2.1.1 (e5) DFA2.2.3 (e7) DFA4.1.2 (e10) DFA4.1.5 (e7) DFA4.2.5 (e7) DFA4.2.6 (e5) DFA5.2.2 (e7) DFA5.2.3 (e8,e9) DFA5.2.5 (e8) DFA5.4.1 (e4) DFA5.4.3 (e9) DFA5.4.4 (e9)	DFA1.2.5 (e3,e7) DFA1.2.6 (e3,e10) DFA2.1.5 (e7) DFA2.2.1 (e7) DFA4.1.7 (e11) DFA4.2.1 (e7) DFA5.1.1 (e3) DFA5.1.3 (F8,F9) DFA5.1.4 (e7) DFA5.2.1(e3,e10) DFA5.3.1 (e3) DFA5.3.2 (e3,e7) DFA5.3.3 (e3,e7) DFA5.4.5 (F8,F9)	MD3. (e9) MD4. (e2,e6) MD5. (e3,e4) MD6. (F9) MD7. (F9) MD8. (e3,e5) MD10. (e7) MD13. (e3) MD14 (e5) MD15. (e2)	UU1. (e3,e4) UU4. (e9) UU7. (e2,e6) UU8. (e3,e5)	UD1a. (e1) UD1b. (e1) UD1c. (e1) UD1d. (e2) UD2c. (e5) UD3a. (e3) UD3b. (e4) UD3d. (e3) UD4b. (e7) UD4c. (e7) UD4d. (e7) UD4e. (e7) UD6a. (e12) UD6b. (e10) UD6c. (e10) UD6d. (e10) UD7c. (e11)	e1 e2 e3 e4 e5 e6 e7 e8 e9 e10 e11 e12	Micro Environment – e
	DFA1.1.2 (E1) DFA4.2.3 (E1,E3) DFA4.2.4 (E1,E2)	DFA1.1.1 (E1) DFA2.1.5 (E3) DFA4.1.10 (E4)			UD7a. (E1) UD7b. (E2) UD7d. (E4)	E1 E2 E3 E4	Macro Environment-E

2.2.1.1.3 Inclusion Criteria

The final version of UDMIG v.2.0 included all of the guidelines, either in whole or modified, from UU and MID. Three UD guidelines (UD 7a, b, d), which applied to the context of use, were taken out of the final set of UDMIG v2.0. This version also included 43 of the 52 (82.7%) guidelines from DfA. Five DfA guidelines were excluded because they guided the design of the environment and four other guidelines were excluded because they applied specifically to desktop interfaces (Table 9).

As an example, half of the Eight Golden Rules of Interface Design (i.e., enable frequent users to use shortcuts, offer informative feedback, design dialogs to yield closure, and support internal locus of control) were included in whole as they apply to mobile devices (Ljilja Ruzic, Lee, Liu, & Sanford, 2016). In contrast, the other half of the guidelines (i.e., consistency, reversal of actions, error prevention and simple error handling, and reducing short-term memory load) were modified to fit the touchscreen mobile environment. In addition, four UD guidelines that refer to the low physical effort (principle six) and one guideline that considers size and space for approach and use (principle seven) were slightly modified to fit the mobile touchscreen environment.

Table 9 – Proportion of design guidance retained from each of the contributing sources

Design Guidelines Analyzed	**Number of Guidelines**	**Number (%) of Guidelines Included in UDMIG v2.0**	**Number (%) of Guidelines Modified in UDMIG v2.0**
Universal Design	30	27 (90%)	3 (10%) excluded 5 (16.7%) slightly modified
Design for Aging	52	43 (82.7%)	9 (17.3%) excluded
Universal Usability	8	8 (100%)	4 (50%) modified
Guidelines for Handheld Mobile Device Interface Design	15	15 (100%)	0 (0%) modified

2.2.1.2 Final Guidelines

Figure 1 presents the UDMIG v.2.0 including the physical environment guidelines, which were taken out of the final version of the guidelines to focus on the design of the user interface. The final UDMIG v2.0 were organized into general (interface structure) and specific (design elements) guidelines (Table 10). General (interface structure) guidelines guide the design of the overall interface, which is the context of use. These guidelines are concerned with the design of the mobile touchscreen interface as a whole. For example, a user interface needs to be designed to be usable by all people, regardless of their abilities and limitations. Specific (design elements) guidelines guide the design of the particular design elements within the mobile interface that users interact with. For instance, a user interface is designed to provide sufficient font size (e.g., font size should be at least 12-

point serif or sans serif fonts, and preferably 14-point size). These are the characteristics of the interface design features.

Table 10 – UDMIG v.2.0

General (Interface Structure) Guidelines	**Specific (Design Elements) Guidelines**
1. Choice in methods of use	1. Same means of use
2. Range of literacy and language skills	2. Design appealing to all
3. Right-, left-, or no-handed use	3. Simple and natural use
4. Adaptation to users' pace	4. Consistency with expectations
5. Minimization of hazards and unintended actions	5. Accuracy and precision
6. Informative feedback	6. Internal locus of control
7. Different modes of use	7. Maximized "legibility" of essential information
8. Simple error handling	8. Clear and understandable navigation structure
9. Easy reversal of actions	9. Dialogs that yield closure
10. Multiple and dynamic contexts	10. Low physical effort
	11. Variations in hand and grip size
	12. Natural body position

Source: (Ruzic & Sanford, 2017)

UDMIG v.2.0 were developed to help with the mHealth interface design for the aging population. In addition to the interface itself, the context of use and its environment are important as well. Four guidelines initially called environment, addressed the appropriate lighting and glare, adjustable positioning, minimized background noise and reverberation, and space for the use of assistive devices. *Environment guidelines* describe those guidelines that direct the design of space in which the mobile interface is used. For example, eyes of older adults admit about one-third of the light to the retina under low-light conditions than the eyes of the young adults. Therefore, the *environment guideline 1*: Appropriate lighting and glare requires adequate lighting, minimized glare (Fisk et al., 2009), a clear line of sight to important elements (Sanford, 2012), and adjustable display when feasible (Fisk et al. 2009). *Environment guideline 2*: Adjustable positioning requires adjustable height, depth, width, and angle from a standing or seated position for a comfortable reach to all components. Appropriate size and space should be provided for approach, reach, manipulation, and use regardless of the user's body size, posture, and mobility (Sanford, 2012) and adjustable display when possible (Fisk et al., 2009). *Environment guideline 3* states that minimized background noise and reverberation should be provided for understanding audio output (e.g., use sound-absorbing materials on walls, ceilings, and floors; provide wireless headphones in public settings; avoid background music during spoken language) (Fisk et al., 2009). *Environment guideline 4*: Space for the use of assistive devices requires adequate space to accommodate independent and assisted use (Sanford, 2012). When multiple devices are required, consider the issue of "homing," moving the hands to the home row key position, following use of the pointing device (Fisk et al., 2009).

2.3 Summary

As people age, they experience declines in both health and function. This not only suggests that mHealth applications are a potential means to meet seniors' health-related needs but also that their usefulness is dependent upon the usability of the application interfaces to fit users' abilities. Whereas UD, DfA, UU, and MID are design strategies that are used to guide the design of mobile interfaces, none are sufficiently comprehensive to ensure that mHealth user interfaces will be usable by older adults. Adaptation and addition of some of the guidelines were necessary to accommodate design for the interactive mobile interfaces for older adults.

UDMIG v.2.0 (Ljilja Ruzic, Harrington, & Sanford, 2017) are an inclusive and comprehensive set of guidelines developed to guide design processes of mobile eHealth interfaces for the aging population. The final guidelines are divided into interface structure and design elements guidelines. Interface structure (general) guidelines relate to the design of the overall interface, and design elements (specific) guidelines guide the characteristics of the specific features of the user interface.

CHAPTER 3. REFINEMENT OF THE UDMIG

The purpose of this chapter is to address specific aims 2 and 3 by developing the mHealth application for people aging with MS, to answer research questions 2 and 3, and to refine the UDMIG v.2.0 to include individuals aging with disabilities. Research Question 2: *What are the health and wellness self-management needs among people aging with MS and related functional features in mobile applications that meet those needs?* To answer Research Question 2, I identified the health and wellness needs for self-management in people aging with the condition, and the related functional features in mobile applications to meet those needs through qualitative study (i.e., focus groups). Research Question 3: *What are the design characteristics of the important design elements in mHealth user interfaces for people aging with MS?* To answer Research Question 3, I evaluated the usability of two current MS-specific mHealth apps and one mHealth app for the general population to identify the barriers and facilitators to usability and provide recommendations for the design of mobile interfaces for the target population through mixed-methods study (i.e., usability testing and semi-structured interviews with the users).

3.1 Development of the mHealth Application

To answer research questions 2 and 3, I present the background for the development of the mHealth application, a systematic review of the functional features in mobile applications for people with MS, and two formative studies that informed the app design and the UDMIG v.2.0 refinement.

3.1.1 Background and Related Work

The purpose of this section is to provide an overview of MS, to define disability, to answer why MS was used as an example of a condition that is characterized with multiple functional limitation and disabilities, and to provide a systematic review of MS-specific mobile applications and their functional features.

3.1.1.1 MS Overview

MS is a complex inflammatory disorder of the central nervous system (CNS). This chronic and progressive condition is affecting around 400,000 individuals in the US and 2.5 million people worldwide, with approximately 10,000 newly diagnosed cases of MS annually. It is a leading cause of neurological impairment (Moses Jr, Picone, & Smith, 2008).

The prevalence of MS varies widely according to geographic areas, with the highest incidence at the extremes of latitude in the Northern and Southern hemispheres (Moses Jr et al., 2008). In addition, women are more susceptible to develop MS with a female to male ratio of 2:1 in most populations. Although the exact cause of MS is still unknown, research shows that it happens due to the interaction between genetics, infectious agents, and other environmental factors in susceptible individuals. The onset usually happens in people 20 to 30 years of age, and the condition has a chronic pattern of relapses (i.e., acute neurological symptoms) followed by remissions (periods of stability). The duration, progress, severity, and symptoms during the relapses vary greatly and are unpredictable. This progressive disorder with repeated relapses leads to permanent physical and cognitive disability.

There are four forms of MS: relapsing-remitting (RRMS), secondary progressive (SPMS), primary progressive (PPMS), and progressive relapsing (PRMS). The most common form of MS is RRMS with over 85% of individuals with MS being diagnosed with this form of MS. The people with RRMS have clearly defined relapses followed by remissions. SPMS is the second phase of this neurodegenerative condition followed by the years of nerve and muscle deterioration. In this phase, remissions become less frequent and replaced by a decline in neurologic function over longer time periods. These individuals have mobility issues and need a walking aid and a wheelchair. 10%-15% of individuals with PPMS have a progressing condition and accumulation of disability without defined relapses or remissions. The rarest form of MS is PRMS, which has a steady decline of neurologic function with short periods of acute exacerbations of symptoms.

MS is characterized by a large number and variety of symptoms (Fraser et al., 2013). Cognitive changes and mobility limitations (e.g., spasticity, weakness in one or more limbs, gait difficulties) are the most significant ones related to disability (Fraser et al., 2013). Other common symptoms include fatigue, depression, chronic pain, sleep disturbances, bladder and bowel dysfunction, numbness or tingling, vertigo and dizziness, emotional changes, sexual problems, and visual impairments (e.g., blurred vision, poor color contrast or color vision, pain on eye movement) (Fleming & Pollak, 2005; Fraser et al., 2013; Gulick, 1998; Rompani & Dua, 2008). These symptoms vary widely from an individual to an individual and within an individual over time.

3.1.1.2 Aging with MS

A majority of individuals diagnosed with MS experience major decline in their abilities due to the progression of MS after five years post-diagnosis and after age 40 (Gulick, 1998). Following this period, they need to learn how to cope with the functional limitations and disabilities caused by the condition and how to age with MS due to an early onset of age-related problems (Fleming & Pollak, 2005; Gulick, 1998). In addition to the signs of early aging caused by MS symptoms and consequent impairments, these individuals experience increased disability due to the physical effects of aging and comorbidities (DiLorenzo, 2011; Finlayson, Van Denend, & Hudson, 2004).

Moreover, MS presents with chronic symptoms that share many of the functional limitations associated with aging, including decline in muscle strength, problems with balance, weakness, fatigue, reduced sensation, vision impairments, bowel and bladder dysfunction, cognitive impairment, pain, osteoporosis and sleep disturbances (Finlayson, 2002; Fleming & Pollak, 2005; Stern, 2005; Stern, Sorkin, Milton, & Sperber, 2010).

3.1.1.3 Disability

The Americans with Disabilities Act ("Americans With Disabilities Act of 1990,") defined the term “disability” as follows with respect to an individual having “a physical or mental impairment that substantially limits one or more of the major life activities of such individual.” The Bureau of Labor Statistics in “Persons with a Disability: Labor Force Characteristics” (Statistics, 2012) defined a person with a disability as one that has at least one of the following conditions: is deaf or has serious difficulty hearing; is blind or has serious difficulty seeing even when wearing glasses; has serious difficulty concentrating, remembering, or making decisions because of a physical, mental, or emotional condition; has serious difficulty walking or climbing stairs; has difficulty dressing or bathing; or has difficulty doing errands alone such as visiting a doctor´s office or shopping because of a physical, mental, or emotional condition.

The International Classification of Functioning, Disability and Health (ICF) (Organization, 2001) is a framework that provides a unified and standard language for describing health and disability and defines components of health and health-related components of well-being. The domains of the ICF are defined by two umbrella terms: “Functioning,” which incorporates all body functions, activities, and participation; and “Disability,” which includes impairments, activity limitations, and participation restrictions. Environmental factors make up the physical, social, and attitudinal environment and can act as either barriers or facilitators to functioning. Personal and environmental factors are components of the contextual factors.

3.1.1.4 Disability and MS

Among a large number and variety of symptoms that characterize MS, cognitive impairments and mobility limitations are the most significant ones related to disability (Fraser et al., 2013). Even though MS varies from an individual to an individual, progressive disability remains the characteristic experience for most people diagnosed with the condition (Chruzander, 2014).

The prevalence of cognitive impairments in individuals with MS ranges from around 40% to 70% (Amato et al., 2010; Chiaravalloti & DeLuca, 2008; Einarsson, Gottberg, Von Koch, et al., 2006; Langdon et al., 2012; Ytterberg, Johansson, Andersson, Holmqvist, & von Koch, 2008). Cognitive impairments are present in all stages and severity of the condition (Chiaravalloti & DeLuca, 2008; Glanz, Healy, Hviid, Chitnis, & Weiner, 2012) and the proportion of individuals diagnosed with MS that have cognitive impairment increases over time (Amato, Ponziani, Siracusa, & Sorbi, 2001).

MS is characterized with an impaired manual dexterity to grasp, lift, and grip in dynamic tasks (Gorniak, Plow, McDaniel, & Alberts, 2014; Krishnan, De Freitas, & Jaric, 2008; Marwaha, Hall, Knight, & Jaric, 2006) and to pinch and grip in common everyday tasks (Chen, Kasven, Karpatkin, & Sylvester, 2007). The prevalence of manual dexterity limitations in people with MS ranges between 73 to 76% (Einarsson, Gottberg, Von Koch, et al., 2006; Johansson et al., 2007).

Individuals with MS experience walking limitations that are characterized with gait abnormalities (e.g., reduction in walking speed, shorter stride, and prolonged double support phase) (Benedetti et al., 1999). The prevalence of walking limitations in individuals with MS ranges from around 43% to 92% (Einarsson, Gottberg, Von Koch, et al., 2006; Johansson et al., 2007; Nilsagård, Gunnarsson, & Denison, 2007). The use of the walking aids is very common in people with MS. For example, researchers (Nilsagård et al., 2007) reported that 73% of individuals with MS used walking aids indoors and 77% used walking aids outdoors.

Individuals with MS experience additional aspects of disability, such as limitations in activities of daily living (ADL), that include difficulty dressing, eating, bathing, transfer from bed to chair, continence, and toileting (personal ADL), and difficulty doing errands alone (instrumental ADL) (Khan & Pallant, 2007; Månsson Lexell, Iwarsson, & Lexell, 2006). Around 50% of individuals with MS experience limitations in personal ADL (Einarsson, Gottberg, Fredrikson, Von Koch, & Holmqvist, 2006; Johansson et al., 2007) and around 70% in instrumental ADL (Chruzander et al., 2014). Researchers (Beckerman et al., 2013; Gulick, 1998) reported that limitations in ADL happen soon after diagnosis and they increase over time.

3.1.1.5 Effect of MS on QOL

MS has significant consequences on their QOL (Rompani & Dua, 2008; Yamout et al., 2013). People with MS experience a large number of physical, cognitive, and emotional challenges on a daily basis (Janssens et al., 2003; Rae-Grant et al., 2011). The majority of people with MS reported their physical health limited daily activities and caused them to accomplish less than they wanted (Minden, Frankel, Hadden, Srinath, & Perloff, 2004).

Ploughman et al. (2012) found that older adults with MS identified disabling symptoms, social isolation, and unpredictability as negative aspects of aging with MS. They were less concerned with increased dependence and disability as a result of MS but were more anxious about the other comorbid conditions, such as cardiovascular condition, depression, and cancer. In addition, they experienced problems with participation in activities, such as exercising, due to the fatigue.

Overall, the major problems people living with MS experience are the lack of social support, MS-related resources and education, and accessibility and availability of disease-modifying treatments (Rompani & Dua, 2008).

3.1.1.6 Self-management for People with MS

As a result, they have to manage the effects of the condition on their lives every day (Fraser et al., 2013). More specifically, they need a continuous condition, symptom, and medication management, coupled with education and effective strategies for addressing the exacerbations (i.e., a worsening of old symptoms or an onset of new symptoms for at least

24 hours, also called a relapse) (Rae-Grant et al., 2011). They need to understand their condition to take charge of managing MS and related impairments (Rae-Grant et al., 2011).

Self-management can help mitigate the symptoms associated with MS (Bishop & Frain, 2007; Bombardier et al., 2008; Fraser et al., 2013; Knaster, Yorkston, Johnson, McMullen, & Ehde, 2011; Stuifbergen, Becker, Blozis, Timmerman, & Kullberg, 2003). To support self-management, access to pertinent information, resources, and education about the nature of MS, the treatment, and methods for improving quality of living (QOL) delivered in an appropriate way could considerably improve lives of individuals with MS (Rompani & Dua, 2008). Additionally, research studies (Finlayson, Preissner, Cho, & Plow, 2011; Mohr et al., 2005; Mohr et al., 2000) suggested that self-management interventions using telehealth (i.e., remote-patient monitoring) have a potential for overcoming access barriers in MS. Social support is another way of enhancing the QOL in people with MS. Moreover, the World Health Organization (WHO) (Rompani & Dua, 2008) and the Consortium of Multiple Sclerosis Centres (Ploughman et al., 2012) advise that individuals with MS take control of decisions affecting their wellness and life and self-manage their condition as often as possible. As a result, there is a great need for efficient tools to support the health and wellness self-management of daily activities for individuals with MS.

3.1.1.6.1 Self-management

Initially, self-management has been defined within the chronic care model (Wagner, 1998; Wagner et al., 2001) that describes self-management support as a method for healthcare providers to teach and empower individuals to manage their health. During the last forty years, the definition of self-management has been changed and adapted many times (Corrigan & Adams, 2003; Ryan & Sawin, 2009). It evolved into self-management as daily supervision and management of the chronic condition carried out by the individuals living with the condition, instead of the healthcare providers (Lorig & Holman, 2003) with the focus on the individual's self-management activity, and not the health systems intervention or education. The goal is to teach individuals with the chronic condition the following primary tasks: 1) medical symptom management (e.g., taking medications, following a diet, using medical devices), 2) role management (i.e., maintaining, changing, and creating new meaningful behaviors and responsibilities, such as adopting new leisure activities, changing duties in household), and 3) emotional management (e.g., adapting to situation-induced emotions including fear, anger, sadness, or grief) (Holman & Lorig, 2004).

3.1.1.6.2 Self-management in People with MS

Research about the self-management of individuals with MS is limited. Researchers (Bishop & Frain, 2007) evaluated self-management behavior among the individuals with MS and reported a strong correlation between self-management and perceived control. In addition, they found that self-management and perceived control mediate the relationship between the physical and emotional impact of MS and QOL. Another study (Knaster et al., 2011) identified the need for individualized self-management support in people with MS that acknowledges the complexity of symptoms they manage and that enables them to manage the impact of those symptoms. There are a few studies which report promising results for self-monitoring interventions for individuals with MS. One study (Stuifbergen et al., 2003) reported significant improvements in self-efficacy, health behaviors, and certain aspects of QOL between women with MS after eight weeks of wellness intervention. Another study (Bombardier et al., 2008) conducted the motivational interview-based intervention in six sessions in which participants demonstrated an increase in health-promotion activities, which include physical activity, stress management, and spiritual growth. Mohr et al. (2005; 2000) reported the benefits of cognitive-behavioral therapy via telephone in reducing depression. In a six-week study (Finlayson et al., 2011) the fatigue management intervention was delivered by teleconference calls to small groups of individuals with MS, and fatigue impact was reportedly reduced relative to a wait-list control group. This study and two previous studies conducted by Mohr et al. (2005; 2000) suggest that self-management interventions using telehealth (i.e., remote-patient monitoring) have a potential for overcoming access barriers in MS.

3.1.1.7 Technological Support for People with MS and Other Chronic Conditions

Recently, mobile technologies have been developed that integrate assistive (AT) and information technologies (IT), potentially providing better solutions for older adults and people with disabilities (Harris, 2010). There is a growth in this technology convergence (i.e., the integration of IT and AT) that came with the popularity of the mobile technologies (Agree, 2014). Individuals with ranges of motor disabilities are adopting touchscreen devices, they are using them on a daily basis, and they think that these devices empower them and help them be independent (Anthony, Kim, & Findlater, 2013). However, they often use customized devices and configurations, suggesting that there is a need for the improvement of accessibility in these devices.

In addition, there have been a number of clinical studies that reported the benefits of the technologies in managing singular impairments that characterize MS, such as mobility, balance, and cognition (De Giglio et al., 2016; Lange et al., 2010). Specifically, these studies support the benefits of video games and virtual reality (VR) for individuals with chronic conditions leading to balance and mobility problems, including population aging with and into a disability (Lange et al., 2010). Following 10 weeks of Xbox 360® and Kinect console use for 20 minutes per session, four days per week, individuals with MS improved balance and postural control (Ortiz-Gutiérrez et al., 2013). After 10 weeks of Nintendo™ Wii use for 20–30 minutes, individuals with systemic lupus erythematosus had reduced fatigue, weight, and waist circumference (Yuen, Holthaus, Kamen, Sword, & Breland, 2011). People with Parkinson's disease had significant improvements in mobility following 4–6 weeks of Nintendo™ Wii Fit balance board use (Esculier, Vaudrin, Bériault, Gagnon, & Tremblay, 2012). In healthy older adults, improvements in balance and mobility were reported following Nintendo™ Wii Fit use 20–40 minutes, two to three times per week over 6–10 weeks (Donoghue & Stokes, 2009). After using three 40-minute VR-based video game (Wii) sessions per week for 12 weeks, participants with cognitive decline experienced improvement in the outcomes in terms of balance, depression, and QOL (G.-H. Lee, 2016). VR technology with specialized interface devices was used to improve motor skills including reaching (Crosbie, Lennon, McNeill, & McDonough, 2006; Dvorkin, Shahar, & Weiss, 2006; Sanchez et al., 2006), hand function (Adamovich et al., 2005; Broeren, Rydmark, & Sunnerhagen, 2004; Merians et al., 2002; Merians, Tunik, & Adamovich, 2009; J. C. Stewart et al., 2007), and walking (Baram & Miller, 2006; Fung et al., 2004; Rivaetal, 1998).

More than half of all individuals living with MS have cognitive impairment (Charvet et al., 2016). Playing specific video games strengthens neural connections in the brains of people with MS and increases their cognitive abilities (De Giglio et al., 2016). During 8 weeks, participants with MS played a video game console and the Italian version of a video game (Dr. Kawashima's Brain Training; Nintendo, Kyoto, Japan http://www.nintendo.it/Giochi/Nintendo-DS/Brain-Training-del-Dr-Kawashima-Quanti-anni-ha-il-tuo-cervello) for 30-minutes, five days per week, and experienced significant increases in functional connectivity in brain areas involved in cognition (De Giglio et al., 2016). An adaptive computer-based cognitive training program enhanced cognitive functioning in individuals with MS after playing their assigned game for 1 hour per day, five sessions per week, over 12 weeks (Charvet et al., 2016). Games Lumosity ("Lumosity," 2016), MyBrainGames ("MyBrainGames," 2016), and CogniFit ("CogniFit," 2016) are designed specifically for improving cognition in people with MS. Physical and cognitive decline in older adults affect their stepping abilities and increase the risk of falls (Schoene et al., 2013). After eight weeks of playing a step pad system exergame as often as they liked with a recommended 2–3 sessions per week for 15–20 minutes each, older adults experienced a significant improvement in their physical and cognitive abilities.

3.1.1.8 mHealth Applications and People Aging with MS

However, these technologies focus on a singular impairment (e.g., balance, mobility, or cognition impairments). As a result, mobile health (mHealth) applications offer potential holistic support for self-management of the condition as they represent more robust technologies that have potential to include all the interventions proven to be useful to manage multiple health problems (Zulman et al., 2015). mHealth self-monitoring applications offer a range of tools to assist with health and wellness daily organization, communication with the healthcare providers, and education (Zulman et al., 2015).

3.1.1.9 A Systematic Review of the Functional Features in MS-Specific Mobile Applications

In this section, I present the search strategy I used to extract the MS-specific apps, and I detail the analysis of these mobile apps based on their functional features to present the limitations in their functionality and a research gap that addresses the needs of the end-user population.

3.1.1.9.1 Methods

To identify the functional features in mobile applications for people with MS, I conducted a systematic review starting with a search strategy to find all the apps for this user population. I then developed a set of valuable features in mHealth apps, extracted the information about the consumer MS-specific apps from the app stores (iTunes and Google Play) and the app websites, and downloaded all the apps to further explore their functionality.

3.1.1.9.2 App Search Strategy

The search was conducted on the Google Search (Google LLC) first and the online app stores, iTunes (Apple Inc) and Google Play (Google LLC). I searched iTunes and Google Play app stores between November 11, 2015, and December 20, 2015. The following search terms were most useful in finding the apps during the initial stage: “multiple sclerosis,” “ms,” “ms diary,” “ms journal,” “multiple sclerosis health,” “ms health,” “multiple sclerosis tracker,” “ms tracker,” “multiple sclerosis management,” “ms management.”

3.1.1.9.3 MS-Specific Mobile Applications

I found nine consumer apps, which provide only basic functionality that can be found in other health apps for the general population and individuals with other chronic conditions (Figure 3).

Multiple Sclerosis Association of America (MSAA) released a mobile app for health self-reporting, *My MS Manager*, for individuals with MS and their caretakers ("My MS Manager ™," 2012). Similarly, *MS self* offers a journal that can be later easily accessed by the user who can share their data with the healthcare team ("MS self – Multiple Sclerosis (MS) App," 2015). Another self-reporting app is called *MySidekick for MS* ("MySidekick for MS," 2012), which also provides medicine reminders and a memory exercise. *My MS Conversations* provides an interactive group session with experienced virtual individuals with MS on selected topics ("My MS Conversations™," 2014). *MS Journal* is injections and medications reminder tool for individuals with MS and their caregivers ("MS Journal," 2014). *My Multiple Sclerosis Diary* ("My Multiple Sclerosis Diary," 2015) is another injections reminder mobile app that offers injection location and time set up to manage taking injectable medicines. *SymTrack* was designed as a health self-reporting tool that stores shares the health charts with healthcare providers ("SymTrac," 2014). Social app *MS Buddy* ("MS Buddy," 2016) pairs individuals with MS with another person with MS to chat daily. *MS Attack* app ("Multiple Sclerosis Attack App," 2014) helps users learn about MS symptoms, how these present themselves during the MS attack, and provides a location of the UT MS Clinic and the Neuro Eye Center.

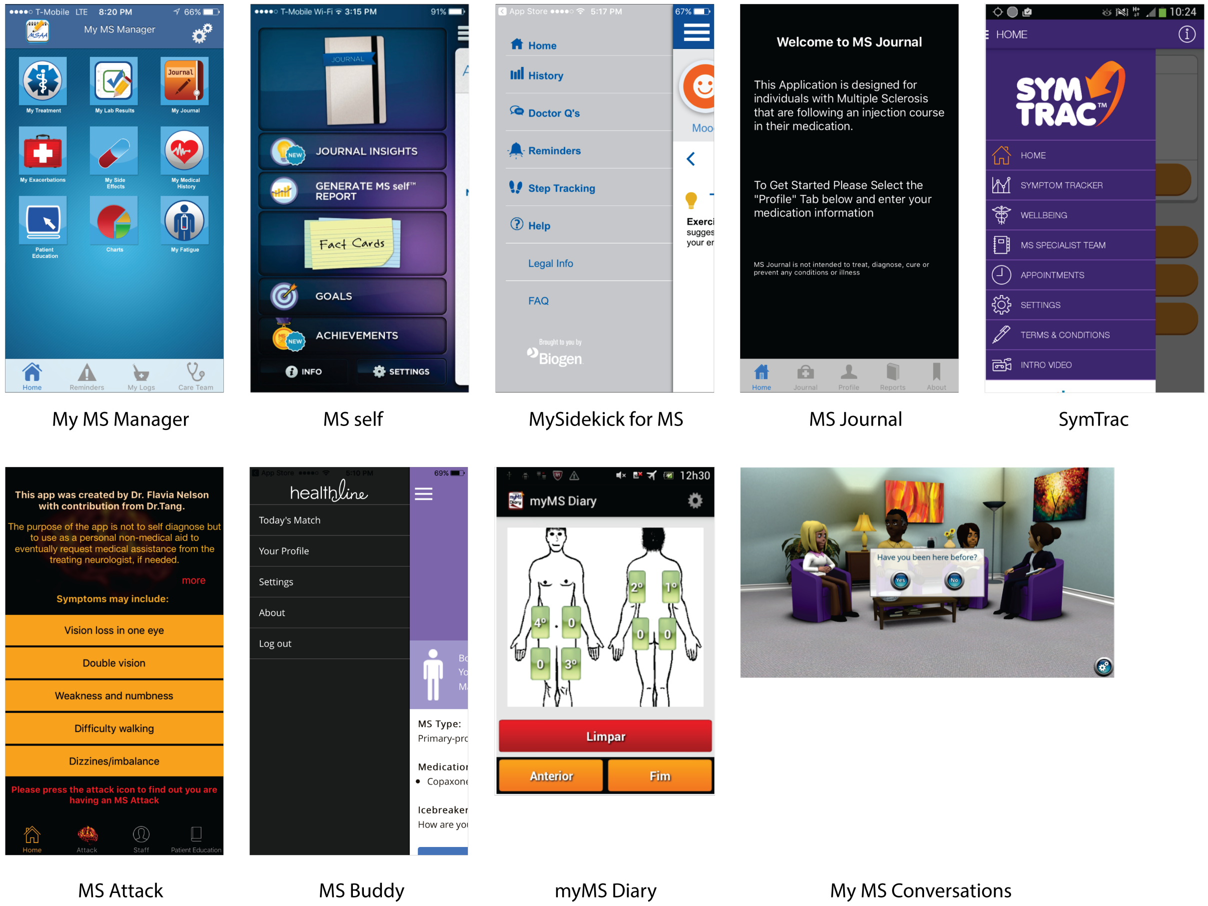


Figure 3 – Current mobile apps for people with MS: MS Buddy ("MS Buddy," 2016), MS Attack ("Multiple Sclerosis Attack App," 2014), MySidekick ("MySidekick for MS," 2012), myMS Diary ("My Multiple Sclerosis Diary," 2015), My MS Manager ("My MS Manager ™," 2012), MS self ("MS self – Multiple Sclerosis (MS) App," 2015), MS Journal ("MS Journal," 2014), SymTrack ("SymTrac," 2014), and My MS Conversations ("My MS Conversations™," 2014)

3.1.1.9.4 Methods for Identifying the Functional Features

To identify the specific functionality needs for individuals with MS, I focused on the health and wellness self-management features in the mHealth applications and did not include the app features that related to general "settings" options (e.g., snooze option, sound effects), usability issues, or cost. Based on a review of the mHealth apps, I developed a list of functional features (Mendiola, Kalnicki, & Lindenauer, 2015) (Table 11).

I extracted the information about the nine MS-specific apps from the app stores (iTunes and Google Play) and the app websites and downloaded all the apps to explore their functionality and to manually assess for the presence of the previously identified features (Table 11).

Table 11 – The initial list of the important functional features in mHealth apps

Functional Features	**Description of the Feature**
Health and wellness self-reporting (journal)	A self-management feature that lets users to record information with a goal to track and understand the condition and modify personal behaviors to achieve a preset goal
Health and wellness tracking using wearables	A self-management feature that connects the app to the wearable(s) to track and collect the health data
Creating and sharing the reports	Feature that stores the self-reporting and tracking data, create charts and reports, and allows the user to send this data to a healthcare provider (e.g., email)
Education	Feature that offers educational resources and information about a condition, including condition-specific news, research, and tips
Goals (plan or orders)	Feature that provides a strategy for an action to reach health and wellness goals, including specific steps to guide the process
Reminders	Feature that prompts the user to take an action and participate in a specific behavior through the use of a preset alert
Community forum	Feature that offers a chat room or a message board for individuals with the condition and caregivers to share experiences and ask questions
Gamification (achievements)	Feature that offers points, badges, and/or different levels of engagement as a health goal is achieved

In addition, I identified other health- and wellness-related features found in these mHealth apps for people with MS (Table 12 and Table 13). In the majority of these mHealth applications, most of the functional features were listed on the homepage. Some additional features were listed within app Settings. For example, *MS self* app had Journal, Reports, Fact cards, Goals, and Achievements listed on the homepage with the Info and Settings. Settings listed Weather Information and Journal Insights as Add-on Features and Syncing the app with Fitbit as Registered User Features. *My MS Manager* had all nine features on the homepage: My Treatments, My Lab Results, My Journal, My Exacerbations, My Side Effects, My Medical History, Education, My Charts, and My Fatigue. I used a binary system to assign either 1 to indicate that a feature was present in an app, or 0 to indicate the absence of a feature.

3.1.1.9.5 Results: Functional Features in MS-Specific Mobile Apps

Three apps were found only in iTunes, one was found only in Google Play, and five were found in both app stores. The user rating range was 2.5 – 4.5, with the mean rating of M=3.54. I identified 23 functional features in nine apps. The median number of features per app was 2.0 (interquartile range 6.5). Only three apps had ≥8 features (Table 12).

The most common features were health and wellness self-reporting (journal), creating and sharing the reports, and MS education. Each of these features was present in 55.56% (5 out of 9) of the apps. The next one is medication/injection adherence in 44.44% (4 out of 9) of the apps. Health and wellness tracking using wearable devices were offered in 22.22% (2 out of 9) of the apps. The remaining seventeen features are each present in only one app (11.11%) (Table 12).

Table 12 – MS-specific mobile apps, number of functional features, user ratings, and operating systems

MS-Specific Mobile Applications	**Number of Functional Features**	**User Ratings**	**Operating System**	**References**
MSAA – My MS Manager	9	3	iOS Android	My MS Manager™ (2012). http://mymsaa.org/manage-your-ms/mobile/. Accessed 11 Dec 2014
MS self – Multiple Sclerosis (MS) App	8	4.5	iOS	MS self – Multiple Sclerosis (MS) App (2015). http://www.moveoverms.org/multiple-sclerosisapp-ms-self/. Accessed 03 Oct 2016
MySidekick for MS	8	2.5	iOS	My Sidekick for MS (2012). https://www.abovems.com/. Accessed 2 June 2015
My MS Conversations	1	3.4	iOS Android	My MS Conversations™ (2014). https://play.google.com/store/apps/details?id=com.syandus.ms_patiented_01&hl=en. Accessed 29 Jun 2015
MS Journal	2	3.5	iOS	MS Journal (2014). http://tensai-solutions.com/app/ms-journal/. Accessed 27 Oct 2014
My Multiple Sclerosis Diary	2	4	Android	My Multiple Sclerosis Diary (2015). https://play.google.com/store/apps/details?id=com.appxient.mymsdiary&hl=en
SymTrac	3	3	iOS Android	SymTrac (2014). http://www.symtrac.com/. Accessed April 2014
MS Buddy	1	3.5	iOS Android	MS Buddy (2016). http://www.healthline.com/health/multiple-sclerosis/ms-buddy. Accessed 14 Nov 2016
MS Attack	2	4.5	iOS Android	Multiple Sclerosis Attack App (2014). https://itunes.apple.com/us/app/multiple-sclerosis-attack/id883546897?mt=8. Accessed 27 Oct 2014

Journal is a most important feature for people with MS that allows users to self-report daily mood, symptoms, mobility, activity, energy, disability, and pain level at one place. This functional feature serves as a notebook, which individuals with MS use daily to self-report their symptoms and related information. Some apps offer to track data using wearable devices. This feature is integrated with Journal to have complete health information stored in one place.

Table 13 – Functional features in MS-specific mobile apps

Functional Features	**Number of MS Mobile Applications in Which Features are Present**
Journal (Health and wellness self-reporting)	5
Creating and Sharing the Reports	5
MS Education	5
Medication/Injection adherence with reminders	4
Health and wellness tracking using wearables	2
Goals	1
Reminders	1
Connecting with individuals with MS (Community forum)	1
Fun Achievements (Gamification)	1
Journal Insight (Journal data observations)	1
Weather Information	1
Add a Treatment	1
Add Lab Results	1
Add Exacerbations	1
Add Side Effects	1
Add Medical History	1
Fatigue Survey	1
Exercises	1
Notepad	1
Memory exercise	1
Suggested questions for doctor appointment	1
MS Clinic Location	1

Journal Insights are observations based on data analysis of the previous journal entries to identify trends and patterns of their symptoms and to help them understand what affects them. Most of the apps have the feature for creating the reports based on the health and wellness data and sharing these with the healthcare providers. Another important functional feature is the social forum, which is present only in MS Buddy, that connects individuals with MS with another person who has MS to exchange their experiences. In addition, there are some apps that offer MS-related education and resources (Table 13). Medication adherence is provided in four apps, and in two of those apps it offers injection adherence as a single functionality. There are 15 additional functional features that are present in only one app.

3.1.1.9.6 Discussion

Although individuals with MS have adopted and accepted mobile applications as a way of receiving the information and support from their healthcare provider for MS management and scheduling appointments on a mobile phone (Haase, Schultheiss, Kempcke, Thomas, & Ziemssen, 2012), the number of mobile apps designed for this user population and their functionality are limited to a small number of features. Moreover, research states that the community forum, telehealth, gamification, and goals, present valuable functional features together with health self-reporting and tracking of data, creating and sending reports, and education (Mendiola et al., 2015). However, none of the mobile applications for people with MS present the holistic and integrative app that provides their users with a variety of these features. Furthermore, there is a lack of literature on needs and concerns of individuals aging with MS (Finlayson, 2002) to inform the design of the mobile technologies and related functional features in MS-specific mobile apps

Consumer MS-specific mHealth applications are limited in their functionality as they offer similar features across the apps and a small number of features within an app. Moreover, none of the apps for people with MS presents the holistic and integrative mobile application that provides their users with a variety of the features including the valuable features in mHealth apps, such as community forum, telehealth, gamification, and goals. These apps fail to deliver a comprehensive self-management tool for end-users' that would help them to understand their condition by monitoring all the factors that can possibly contribute to the symptoms and relapses, by identifying the trigger factors and patterns, and by sending all the data to the healthcare providers with the alerts in a case of emergency or a special need.

3.1.2 The Needs Assessment Study: Health and Wellness Self-Management Needs of People Aging with MS and Related Functional Features in Mobile Applications

To answer RQ2, I conducted qualitative study with individuals aging with MS with the purpose to: 1) understand their health and wellness needs for self-management, and 2) recognize the specific functional features in mobile technologies that meet those needs.

3.1.2.1 Methods

I conducted two focus groups to gather the information about the needs of individuals with MS for their health and wellness self-management and the opportunities for the functionality of the mobile apps to meet those needs. Aging with MS was defined as having been diagnosed with the condition for at least five years.

When the purpose of the focus group study is to gain an in-depth understanding of people's experiences, the researchers recommended smaller group sizes (Krueger, 2014). Moreover, smaller groups are preferable when the participants have a lot of information to share about the topic or have had important or lengthy experiences with the subject of discussion. Following the recommendations for the focus groups size, total of 8 participants diagnosed with MS at least five years ago participated in two focus groups. Focus groups were used as a widely used self-contained research method for gathering qualitative data (Kitzinger, 1994; Morgan, 1996a, 1996b). After discussing their self-management habits, they were introduced to the three selected mHealth applications. The focus of the discussion was to identify the health and wellness self-management needs in individuals aging with MS, related specific functional features in mHealth apps that can address these needs and improve the design of new MS-specific mobile technologies.

3.1.2.1.1 Participants

Participants were recruited through the CATEA Consumer Network (CCN) at Georgia Institute of Technology and snowball sampling. Two groups of 4 participants, with a total of 8 participants were recruited. The inclusion criteria were that participants be of age 18 and older and that they were diagnosed with MS at least five years ago. The characteristics of the two groups of participants are presented in Table 14.

Table 14 – Characteristics of focus group participants

Focus groups	**Female**	**Male**	**Age range (years)**	**Mean age (years)**
Focus group 1	4	0	54-67	59.50 ± 6.14
Focus group 2	2	2	33–59	43.75 ± 11.81

The background questionnaire was administered where participants self-reported their number and types of functional limitations (Figure 4, Table 15).

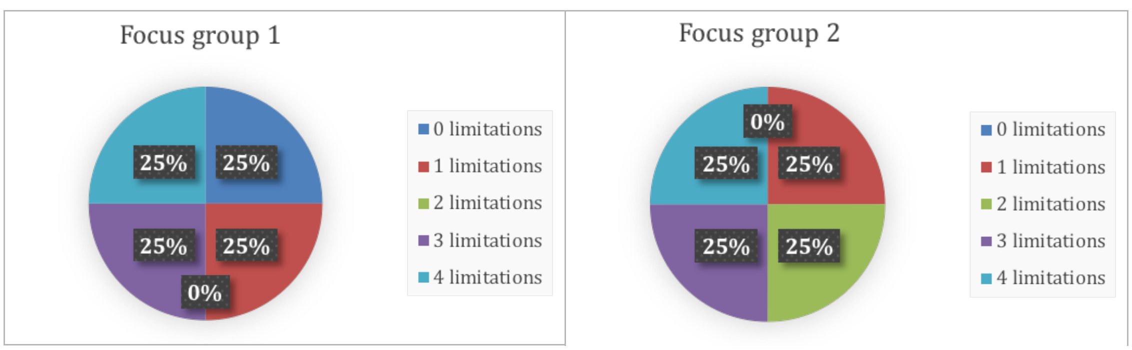


Figure 4 – Number of functional limitations in participants

Table 15 – Types of functional limitations in participants

Focus groups	**Functional Limitations**					
	Fatigue	Dexterity	Pain	Balance	Gait	Numbness
Focus group 1	2	1	1	1	1	1
Focus group 2	0	0	0	1	2	0

Table 15 – Types of functional limitations in participants *(Continued)*

Focus groups	**Functional Limitations**				
	Difficulty Walking	Speech	Tremor	Foot drop	Lower Extremity Weakness
Focus group 1	1	0	0	0	0
Focus group 2	3	1	1	1	1

3.1.2.1.1.1 Use of mHealth and MS-specific Mobile Applications

I asked the participants to rate their use of mobile apps (e.g., Weather Underground: Forecast ("Weather Underground: Forecast," 2017), Skype ("Skype for iPhone," 2017)), mHealth apps (e.g., iHealth, Health ("Health," 2017)), and MS-specific applications (e.g., *My MS Manager*, *MS self*) on a scale from frequently (e.g., a few times a day), often (e.g., once a day), occasionally (e.g., once or twice a week), very infrequently (e.g., once a month), to never (Table 16).

Table 16 – Use of mobile, mHealth, and MS-specific applications in focus group participants

		Frequently	**Often**	**Occasionally**	**Very infrequently**	**Never**
Use of mobile apps	**Focus Group 1**	0	3	1	0	0
	Focus Group 2	0	3	1	0	0
Use of mHealth apps	**Focus Group 1**	0	0	1	3	0
	Focus Group 2	2	0	1	1	0
Use of MS-specific mobile apps	**Focus Group 1**	1	0	0	1	2
	Focus Group 2	1	0	1	1	1

Overall, in both focus groups, participants reported frequent and occasional use of mobile apps, less frequent use of health apps, except for 2 participants who reported that they use these apps often, and even less frequent use of MS-specific apps, except for 2 participants who reported they often use this type of apps. Three participants reported they never used MS-specific app, and 2 used them very infrequently.

3.1.2.1.1.2 Computer and Touch Screen Experience

The participants self-reported their computer and touchscreen experience on a scale from 1 = none, 2 = novice, 3 = intermediate, 4 = advanced, to 5 = expert. The level of computer and touchscreen experience was presented in Table 17.

Table 17 – Computer and touchscreen experience in focus group participants

Focus groups	Computer experience		Touchscreen experience	
	Mean, M	**Standard Deviation, SD**	**Mean, M**	**Standard Deviation, SD**
Focus group 1	4.25	0.96	4.00	0.82
Focus group 2	4.00	0.82	4.25	0.50

3.1.2.1.1.3 Accessibility Features

The participants reported the use of the accessibility features on their smartphones (Table 18).

Table 18 – Use of the accessibility features in focus group participants

Focus groups	Accessibility Features				
	Large text size or zoom	Voice-over	High contrast or inverted colors	Assistive touch	No accessibility features
Focus group 1	3	1	1	0	1
Focus group 2	3	2	0	1	1

3.1.2.1.2 Testing Devices and Mobile Applications

I chose *My MS Manager* and *MS self* for this study as the two most relevant apps for individuals with MS with the highest ratings, widest overall functionality, and the biggest number of features that included health self-management through Journal entries, generating and sharing the reports based on those entries, and education through Journal entries and generating and sharing the reports based on those entries (Table 12 and Table 13). *My MS Manager* had 6 additional (total of 9) functional features including fatigue survey, treatment/medication adherence, lab results (health records), medical history, reporting side-effects and exacerbations. *MS self* had 5 additional (total of 8) functional features, such as health and wellness tracking using wearables (Fitbit), Journal insight, goals, fun achievements (gamification), and weather information. In addition, I chose *iHealth* ("iHealth," 2012) as an integrated mHealth app that connects to wireless health devices (e.g., blood pressure monitor, glucometer, weight scale) via Bluetooth to remotely monitor the health of the general population. This app was introduced to the participants because of its use of telehealth with the purpose to enrich the discussion and expand the possible ways of the health and wellness self-monitoring due to the limitations of the functional features in MS-specific applications (Figure 5).

Three mobile apps were tested on an iPhone 6 device, which has Retina HD display that is 4.7 inches in size with a 16:9 resolution of 1334x750 (326 ppi).

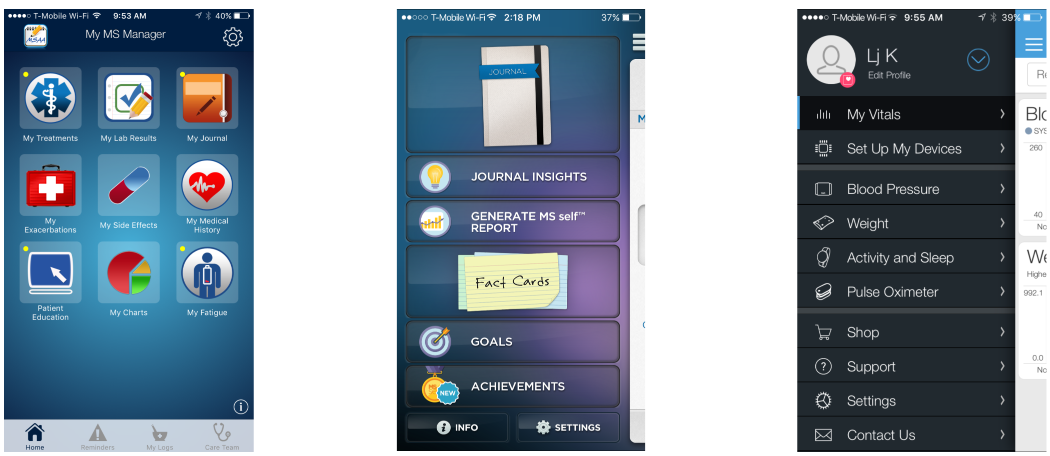


Figure 5 – My MS Manager ("My MS Manager ™," 2012), MS self ("MS self – Multiple Sclerosis (MS) App," 2015), and iHealth ("iHealth," 2012), Respectively

3.1.2.1.3 Procedures

First, participants signed the informed consent form approved by the Georgia Tech Institutional Review Board (IRB) and completed demographic background questionnaire first. Second, they participated in focus groups where participants discussed their needs related to the self-management of health and wellness. Third, they were asked to talk about the possible functional features in mHealth apps that could help address those needs and the opportunities for development of new MS-specific mobile technologies that would help address their identified needs. Fourth, they were introduced to the three apps, *My MS*

Manager, *MS Self*, and *iHealth*, and their functionalities were explained in detail to them for the purpose of further discussing the new ideas for the functional features in mobile technologies. For example, participants used the remote blood pressure monitor with *iHealth* app to understand the functioning of the wireless health monitoring devices. They had time to explore and ask the questions about three introduced apps in a focus group. The study was video recorded and lasted around 150 minutes. All participants were compensated $20.00 for their time and $5 for the travel to Georgia Tech.

Specifically, I asked participants how they manage their health and wellness, what they need and use to self-manage health and wellness daily, what functionalities they would like to have in mobile health and wellness apps that would help them to address those needs and why (suggestions were given after the discussion was exhausted, such as entertainment, games, achievements). In addition, I probed participants with more specific questions to enrich the discussion. I asked them whether they prefer health tracking over self-reporting and which health measurements they would like to have monitored using the wireless health monitoring devices. Moreover, I asked participants to discuss the existing functional features within the MS-specific and health apps if they did not already talk about those to exhaust all the possible functionalities of the mHealth apps. To further motivate the discussion, I asked which features their ideal MS app would have, what would be its main feature, and how often they would use it.

3.1.2.1.4 Data Collection and Analysis

An inductive approach was used for the focus group data analysis. All notes and transcripts were collected and summarized into one document. Atlas.ti was used for data analysis. Two research members generated a preliminary set of codes. Pre-set codes were used for the initial data coding, and emergent codes came out from the secondary reading of the document. The pre-set codes were related to the known functional features (i.e., upper-level themes) in the existing mobile apps. For example, Mood, Diet, Symptoms, Sleep, and

Activity (health and wellness self-reporting and tracking), Health information to reports (creating and sharing the reports), MS news, MS research, Health and wellness tips (MS education), Social support of people with MS, Reminders and alerts were used as the upper-level pre-set themes. In vivo coding was used to generate more upper-level themes. Medication adherence, MS-specific exercises, Health records, and Games and VR emerged from the secondary review of the transcript (Table 19). In addition, a number of other themes emerged, such as Geolocation, Weather update, Telehealth, and Personalization. This model was applied by starting with the familiar functional features in current mobile apps, and by expanding it with the ones participants found useful that does not exist in the current apps.

Table 19 – Code document table for the upper-level themes (i.e., health and wellness self-management needs) and their categorization based on the functionality

Health and Wellness Self-Management Needs	**Number of codes**	**Functional Features**	**Number of codes**
Mood	11	Journal (Health and wellness self-reporting and/or tracking)	48
Diet	10		
Sleep length and quality	7		
Symptoms	7		
Activity	4		
Weather update	3		
Geolocation	6		
Health information reports	26	Reports (Creating and sharing the health information)	51
Medication adherence	11		
Health records	14		
News, research about MS	8	MS Education (MS resources, education, news research, tips)	13
Health and wellness tips	5		
Reminders and Alerts	9	Reminder and alert systems	9
Social support of people with MS	22	MS community forum (Social support)	22
Health tracking	10	Telehealth (Health tracking)	10
Virtual experiences	7	VR and Games (Virtual experiences and games)	7
		MS-specific exercises	5
		Personalization	4

The lower level functional features were grouped into related functionalities. For example, mood, diet, sleep length and quality, symptoms, activity, weather update, and geolocation were grouped into health and wellness self-reporting and/or tracking feature, called journal or diary. MS-specific exercises and personalization emerged as functional features and were not mentioned as health and wellness needs.

3.1.2.2 Results and Design Implications

In this section, the needs for self-management of health and wellness among people with MS and the opportunities to meet those needs with new mobile technologies and specific functional features in mobile applications are reported.

3.1.2.2.1 Health and Wellness Self-Management Needs

Participants talked about a number of needs for health and wellness self-management, which were grouped into 7 main categories.

1. Health and Wellness Self-Reporting and Tracking

Individuals with MS reported that they wrote daily notes, called journal, diary, or report, about their symptoms, exacerbations, and remissions, and the factors that affected them. This is an important health self-management activity they perform on a daily basis. The health and wellness logs helped them learn about the condition, track the progress of MS, be more aware of themselves and their health, and accept having MS.

Participants identified the following factors that need to be monitored daily: diet, mood, activity, sleep, weather, and geolocation together with the symptoms and a part of the body that is affected. For example, P1.1 commented that their diet was *"important because of relapses"* and P2.2 self-reported *"which food makes me more fatigued."* P2.4 said that *"mood, how I am feeling, a weaker area of the body"* is important to report with symptoms, and that *"mood at the beginning and the end of the day"* should be noted down. Similarly, P2.2 commented that it would be *beneficial "to track your emotions, what triggers you."*

2. Creating and Sharing the Health Information, Including the Medical Records and Medications

The primary purpose of collecting these daily health notes is to take these continuous reports to the neurologist so that they could discuss and better understand their condition. Their current practice is to manually collect the notes and bring those to the healthcare provider during the appointment. Participants expressed the need for a more efficient and easier way of communicating the health information to the healthcare professionals.

The secondary purpose of those notes is to help them understand the condition, track the progress of MS, and accept having it. Additionally, they needed a way to learn about the factors that might cause the exacerbations and worsening or decrease of the symptoms, as commented by P2.2:

> *"(I note down) what increases my fatigue, what I eat. I just got a journal. Anything to manage MS is a positive (thing). One day I just rest, another day I have three tasks. What I like to do (is to) keep track of my saturation level, infusion saturation level; record of going up or down."*

Additionally, participants discussed that their medical records helped them visualize the progression of MS and accept having the condition. After being diagnosed with MS, these individuals go through a period of denial. This phase can last many years. However, they understood the importance of the acceptance of the condition, as stated by P1.4:

> *"Medical records are very important because of that image; (it) puts it in perspective."*

Medical records helped them to understand an occurrence of the exacerbations and symptoms, as P1.4 stated:

> *"Blood work information (is important). Based on it (to monitor) progression, painful flare-ups."*

Moreover, the majority of the participants thought that medication adherence was essential. They discussed the importance of recording all the medications and supplements, their schedule, whether they took those, and how they felt after that. The importance of medication adherence is addressed by the WHO (Sabate, 2003). Disease-modifying therapy for MS and other long-term therapies require high levels of medication adherence to deliver adequate outcomes (Hansen et al., 2015). However, researchers reported low levels of adherence to four disease-modifying drugs (DMDs) in individuals diagnosed with MS.

Reminders in the form of text messages have improved adherence in chronic conditions (Thakkar et al., 2016). Recently, there have been a large number of mobile applications developed to improve medication adherence (Santo et al., 2016). However, the researchers found that the majority of these apps do not have the desirable features and are considered low quality. Moreover, only two apps for individuals with MS incorporate medication adherence into the features, *My MS Manger* and *MySidekick*, and two other apps, *My MS Diary* and *MS Journal*, focus solely on injection adherence.

3. MS News, Research, Tips, and Resources

As advised by the WHO (Rompani & Dua, 2008) and the Consortium of Multiple Sclerosis Centres (Ploughman et al., 2012), individuals with MS should take charge of decisions related to their health and life. Moreover, researchers (Köpke, Kasper, Mühlhauser, Nübling, & Heesen, 2009) reported that the education program caused more independent decision making in individuals diagnosed with relapsing MS.

Individuals aging with MS discussed the importance of access to the reliable latest research and news about MS, resources, and the health, wellness and lifestyle tips that would help with the condition. Participants in the second focus group discussed the need for the MS-related resources. P2.4 was a new resident in Georgia and wanted to know where *"to find medical equipment, providers."*

Additionally, they complained about the quality and the content of the MS-related news and research. For example, P2.3 stated that:

"Stats on MS are terrible. It is mostly about drugs, not about MS."

4. Reminder and Alert Systems

All eight participants talked about the need for a reminder and gave examples of their usage. P2.2 needs a place *"to get things done, to remind me. (For example,) a to-do list to manage the day."* P2.4 wanted to *"set a reminder for everything: vitamins, daily things, (and) journal."* They talked about a vibration reminder with the purpose to motivate them to perform an activity and to exercise. P2.3 talked about the benefits of the medication reminders they had and explained the tactics they used to better support their medication adherence and provide an additional reminder:

> *"An alarm reminds me to do it (take medicine). My wife's phone is a backup. I type the message (to her)."*

5. Social Support of People with MS

Having and preserving social connections presents an important aspect that increases QOL in individuals with MS and older adults (Fan, Forlizzi, & Dey, 2012; Rompani & Dua, 2008). Participants in this study were very interested in communicating with other individuals with MS around the world to exchange their experiences of managing and dealing with MS and to get support for everyday challenges with the condition. P2.2 discussed:

> *"Yes, emotionally there are so many things (going on). Being a part of a support group would be helpful, so other people see how I'm doing with MS. I would go to someone else and (we could) help each other."*

6. Telehealth: Health Tracking

Telehealth has been widely accepted, and its importance in promoting and protecting health is reflected in the growth of health tracking systems and applications (Darkins & Cary, 2000; L. Kascak, Rebola, et al., 2013a). After participants discussed remote tracking of their wellness data via Fitbit or similar popular consumer wearable device (e.g., sleep length and quality, number of steps, stairs, and miles, calories) they introduced a need to measure and track other health data. All participants found the need to measure the blood pressure, heart rate, and other vitals very important.

7. Virtual Experiences

Participants talked about their experience of having MS and an emotional side of their journey. They discussed how mobility impairments make them feel different and how people treat them in a special way or do not notice them at all. P1.4 stated that:

> *"While driving a car, no one knows I have MS. I just want to be like everyone else."*

They continued the discussion by expressing the need for experiencing the activities and events they used to be able to perform and attend with their friends and family. The topic of VR was first mentioned by P1.2 during this conversation. This participant had previous experience with playing a VR biking game, and they described this exciting event and how wonderful it felt to be able to perform certain activities again. The other 3 participants in the first focus group agreed that VR games would be of great importance and benefit to them. They wanted to remember what it feels like doing certain outdoor activities. P2.2 stated that:

> *"I get tired fast during outdoor activities, and I get frustrated a lot because of adjusting to walking."*

Having an opportunity to do all these physical activities using the VR was incredibly important to them. Individuals with MS wanted to feel the same and as able as other people, at least in the virtual world.

3.1.2.2.2 The Specific Functional Features in Mobile Applications That Meet Those Needs

Additionally, participants discussed possible solutions to meet and manage those needs through mobile applications. They identified many features that could be adapted or developed, which were grouped into 9 main categories, with the last tenth category presenting their need for the holistic self-management tool that includes the previous features. The first 7 categories represent the potential means of addressing the identified health and wellness needs. The last two functionalities were identified during the discussion about the mHealth app design.

1. Journal

The participants identified a number of factors that have to be monitored together with their symptoms, relapses, and remissions, which should be used to inform them about the progress of MS and provide an overall picture of their condition. They need to learn what affects and causes the symptoms and exacerbations. These everyday self-management tasks include self-reporting or preferably tracking (using wearable devices) of their mood, diet, sleep, activity, whether, geolocation, medications, vitamins, symptoms, and exacerbations. All this information should come together to provide individuals aging with MS with the comprehensive tool for understanding their condition on a daily basis and over time and how best to manage it.

While talking about their needs for health and wellness self-management, some participants suggested that mobile apps could be used as useful tools for self-reporting and tracking the health data instead of taking the notes. P2.1 stated:

> *"I found first a journal (to write what I) eat, (how I) sleep, weather, temperature, and how I felt with this. An app would be a very good tool to help with this information. (For example,) heat sensitivity; when it gets warmer, I have more fatigue."*

They took time to discuss self-reporting and tracking features and thought that *"journaling"* should be the main functional feature of the app. Tracking was preferred to self-reporting. For example, participants wanted to track their sleep to know how long and how well they slept over time because they have a hard time getting back to sleep. Activity tracking was discussed as the beneficial aspect of the wellness tracking system.

Additionally, they discussed the importance of the weather and geolocation features. It was very important for them to understand what affects their symptoms and in what way. Weather is critical for an understanding of the condition because of the effects of the temperature on their fatigue. They need to know if their symptoms happen *"because of geographical (location) and weather reasons"* (P1.1) or because of their diet, sleep quality, and other factors. They suggested that the app provides feedback about their current location so that taking the trips and home location can be associated with the symptoms.

Moreover, they discussed the ways the health and wellness information should be self-reported. All participants preferred the use of the emoticons with a scale. For example, they would like to report the symptoms and mood via *"a face for fatigue with a scale of 1 to 10"* (P2.1).

2. Reports

The participants wanted to have the self-reported and tracked data (using wearable devices) aggregated and presented into charts and graphs so that they can see how MS progresses, learn the patterns, and understand what the factors that affect their condition are. They required this information to be sent to the healthcare providers, family members, and caregivers. Currently, participants collect this data manually and bring it to their neurologists during every visit. Therefore, having the option to send these reports electronically would help them with data accuracy and time-saving. In addition, they wanted to have their medical records available on the app to visualize the progress of MS, understand the condition better, and accept having the condition. Moreover, medication adherence was found important by the majority of the participants.

2.1. Health and Wellness Reports

The participants commented that they need *"holistic information"* (P1.1) as app feedback (i.e., reports, charts). They need to understand what and how many of the self-reported health and wellness data impact their symptoms and affect the relapses and the remissions, as commented by P2.2:

> *"(I need) construct on data we put in, reports on data we put in; I'm already writing it down."*

All participants asked for the report tool to be available to themselves, healthcare providers, and the caregivers. This tool should sum up all the self-reporting and tracking features and provide an overall picture of their health on a daily basis. P1.1 summarized:

> *"If you can print a report and send data to doctor, (that) would be helpful. Generate an overall report to a doctor. Incorporate other accidents and surgeries in a complete report. Patient portal with a doctor to capture all (the) information."*

Participants wanted to print, email, and/or send the reports to their caregivers, family members, and healthcare providers. They did not focus on the nature of the reports and the possible differences in the specifics of the output in this information tool to different users.

Overall, the visualization of the condition progression is incredibly important to them, so that they can learn about it and accept having MS.

2.2. Medical Records

Availability of health records is vital in helping individuals with MS realize whether and how MS progresses. The health records help them accept MS, as described by P1.1:

> *"I can see his (doctor's) notes. I find that helpful. It allows me to be more proactive. It doesn't update real-time. It would be helpful (if it does). A doctor is more involved that way. I like to see how MS progresses. I know that it progresses: from the notes on the first MRI to (the) last one, office visits. It helped me mentally accept it."*

One of the problems with the availability of health records within an app is privacy and data security. All participants in the first focus group appreciated the idea of having their medical records accessible and available within the app. After a neurologist explained the benefits of having this data and recommended the usage of an online tool for its access, P1.2 understood its benefits and wanted to use it. However, all the participants in the second focus group expressed concern over having their medical data on the app. To four of them, health data are personal, and they are afraid of having their medical records exposed and vulnerable within an app. P2.2 discussed her view on the data security:

"Medical records are personal. My preference is in mail vs. having it on the phone, so someone can see it. MRI (records) not on the phone. I'm trying to accept having MS so having medical records is a reminder. I like accessibility, but I like privacy."

2.3. Medication Adherence

In this research study, medication adherence was found important by five out of eight participants. They wanted to keep a record of all the medicines and supplements they took and to know how they felt after taking them. This feedback could help them in deciding about the possible vitamins and change of medication regime. P1.3 suggested a possible use of the medication adherence tool as a feature that would let the users know whether certain medications can be taken together, and if the condition prevents them from taking a number of drugs:

"Does either of apps has (a feature): if we put up medicine information and if medicine conflicts the app tells you that? I don't have time to call. If an app has something like that you put medication name and app pops up with information that that medicine does not interact well with another medicine and similar. (It would be) great to have (information about) what medications affect. For example, a pharmacy app (about) what medications react with what other ones. If you have a condition and take medicine, some other food and medicine may not interact well with them. If that app has that feature, I would use it. How medication affects you, vitamins, (other) medication, and food? (It would be good to know the) side effects of drugs you are taking. How does it affect your mood? Drugs you are taking: are they affecting and what?"

Participants discussed the use of wearable devices as the reminder tools for taking the medications as well as the benefits of medication adherence apps, as P1.2 commented:

"It would help make it (taking the medications) more regular (if taken) with my pill dispenser. I like something that would wake you up vibrating. (For example,)

medical alert bracelets with name and condition, Fitbit with medical information that can be pulled up by emergency people, ICE (in case of an emergency app).”

Additionally, participants reported that having the vitamins on the medications list would be beneficial to them. The list should have all relevant information, including the medication side-effects, dosage, users’ comments on the effectiveness of every medication and supplement, and similar. P2.2 commented:

“Medicine with side effect would be useful; keeping up with different medications and supplements they (doctors) prescribe. App to keep in mind when I took this (medication), this is how I feel, I feel I can supplement this.”

3. MS Education

I found that individuals aging with MS wanted easily accessible latest MS research, news, and resources, with the health, wellness and lifestyle tips, as a source of reliable information about MS. All participants wanted to have valid health information on managing MS symptoms. P1.3 wanted to have a *“health information with a link, information on health tips, lifestyle tips, and tips for healthy brain and cognition.”* P2.3 wanted to have a feature that allows them to call Multiple Sclerosis Association of America (MSAA) to ask whom they recommend as a doctor.

4. Reminders and Alerts

The participants discussed the importance and expressed their interest in having the reminders and the alerts to assist with medication adherence, condition management, and other daily tasks.

In addition, participants discussed the importance of the medical tools with alert features. Four participants in the second focus group wanted a feature similar to *“medical alert bracelets, with name and condition. Something like Fitbit with medical information that can be pulled up by emergency people”* (P1.2).

5. MS Community Forum

Participants talked about the need to communicate with other people diagnosed with MS all over the world to hear about their ways of managing the condition, treatments, and coping skills. Additionally, they wanted support for and a real understanding of their daily challenges with MS. They preferred video calling to talking and texting, as a way of connecting with other people. Moreover, participants suggested having a social tool for activities that connects them with others with MS who would join them in their hobbies and recreation.

All eight participants found having the social support available within the MS-specific app incredibly useful and commented that it would be beneficial *"to share the information with other people with MS"* (P1.1) and experience *"how people outside of US manage MS"* (P2.2).

Talking with headsets was preferred compared to chatting because of the motor and dexterity issues while seeing someone via video call (e.g., Facetime, Skype) was the most favored option for the communication. P1.4 suggested that:

> *"If you are online, there is an indicator (that) you are online, and you can choose what you want: chat (or) talk. It would be fabulous to experience how is MS around the world and have a serious conversation with people who know what you are going through."*

P1.2 wanted a tool that would *"synchronize with someone else to support each other (and) walk together."*

6. Telehealth

The individuals with MS thought that the possibility of remotely tracking their health and wellness data represents an important and convenient tool, especially if an app is connected to Fitbit or similar popular consumer wearable device. All participants found the experience of measuring the blood pressure enormously beneficial. They found the idea of remotely tracking their vitals to be valuable, time-saving, and convenient. P2.3 was already using Fitbit to track the activity (e.g., walking, biking) and sleep and found it incredibly helpful:

"I love it. It does everything for me. It is not that accurate: the miles, steps. It tracks how much I ride the bike. It doesn't fit well the number of miles. It records sleep, how long and how well (I sleep). I had it for three weeks."

The significant finding in this study was that in addition to the remote tracking of the blood pressure, weight, heart rate, sleep, and activity that were present in *iHealth* app, participants talked about the importance of tracking the tremor. Moreover, they expressed a strong opinion about wanting to use wearable devices to track their data as much as possible so that they do not have to self-report and enter data manually because of their motor impairments.

7. Games and VR

Half of the participants wanted to have games and VR available to them within the app. They realized that VR would give them an opportunity to perform the activities that would be challenging in the real world. Participants in the first focus group loved the idea of virtually performing the activities they were unable to do in a real world, such as biking, fishing, camping, and similar. P1.2 commented:

"I like the game aspect. We want others to bike virtually. It (virtual biking game) gave me such a sense of freedom and liberation. Also, virtual fishing and camping. In a virtual world, I would do it."

When asked about the game as a mobile app functional feature, these four participants in the first focus group thought that playing the games would be beneficial to individuals with MS. They thought that the games should be designed to help them with MS symptoms, as stated by P1.1:

"If (the game is) for MS, if it would be beneficial to MS."

The idea of playing the games was very interesting to them. When asked if they would use the medical tests in the form of a game, the same four participants stated they would be interested in doing it.

The other four participants in the second focus group thought that the VR and game functional feature would be *"too overwhelming"* (P2.4). They thought that it goes beyond what the MS app should stand for, as stated by P2.1:

"No, I want more having MS data, the core value."

8. MS-Specific Exercises

Participants wanted to have the exercises specific to the physical needs of people with MS within an app, as P1.4 commented:

"I want an app that I can use exercises. (For example,) exercise tips for wheelchair bound, (such as) simple moving around, shrugging your shoulders, moving your hands. Vibration (would be helpful) to remind you to move a little."

9. Personalization

Individuals with MS wanted to have personalization and customization available to accommodate the differences in opinions, needs, and contexts of use. They wanted to set up the pace of the interaction and their preferences and to prioritize certain functional features. P1.1 talked about self-learning and adapting feature:

"Self-learning: it (the app) would know what I use all the time."

10. Holistic app

Overall, participants wanted a single comprehensive app for self-managing MS that would integrate all the features they discussed. They needed an app that would visualize the condition patterns and timeline so that they could better understand the factors that affect it. All four participants in the second focus group concluded that they want to have one app with a number of functional features, as commented by P2.1:

"One app is great with a journal, alarm, reminder, reliable information, to-do list."

Additionally, participants discussed the availability of the apps on both operating systems (i.e., iOS, Android) and a possibility of having the web version they can use on their computers. P2.4 concluded about the importance and role of health and wellness self-monitoring apps:

"These things help me be aware of myself."

3.1.2.3 Discussion

In this study, participants discussed a number of needs for the health self-management including health and wellness self-reporting and tracking, creating and sharing reports, including medical records and medication adherence, availability of MS news, research, tips, and resources, reminder and alarm systems, social support of people with MS, telehealth (health tracking), and virtual experiences. During the focus group conversations, they talked about the potential support for these needs through mobile technologies and specific functional features. Each of the identified needs resulted in a feature, such as a journal, reports, MS education, reminder and alerts, MS community forum, telehealth, and VR. Additionally, discussion about the VR games expanded that functionality into VR and games, which would include games that improve cognition and balance. MS-specific exercises and personalization emerged as additional functional features that were not mentioned as specific health needs.

Moreover, individuals aging with MS discussed a need for the holistic app that represents a complete health and wellness system and a way to self-manage MS. A comprehensive self-management app would help them understand their condition by recognizing and managing all the factors that possibly contribute to their symptoms and exacerbations, and by keeping records of all the changes and what causes them to identify trigger factors and patterns.

3.1.3 Usability of mHealth Applications for Individuals Aging with MS

To address RQ3, individuals aging with MS and older adults tested the usability of two MS-specific mHealth apps (*My MS Manager* and *MS self*) and one for the general population (*iHealth*). Researchers (Bryman, 2006; Greene et al., 1989) reported that mixed-methods research approach achieves a greater validity, offsets the weaknesses of both methods and draws on the strengths of both, provides more complete results, enhances integrity of findings and improves their usefulness. I integrated a quantitative and qualitative methods through the use of usability testing and semi-structured interviews to enrich the quality and the amount of data and provides more complete results. Usability testing was used to identify design elements and their characteristics, which either act as barriers or facilitators to usability for both groups of participants. Semi-structured interviews were used to further extract more data about these characteristics and to identify greater number of design elements important to the end-user population. The focus of the study was to recognize the characteristics of salient design elements of the interfaces, such as font and button size, use of the picker, navigation bar and similar, which either act as barriers or facilitators to usability for both groups of participants. These design elements were used to provide the recommendations for the design of mobile apps for people aging with MS.

3.1.3.1 Methods

I conducted usability testing with two groups of participants, individuals aging with MS and older adults, to test current mHealth interfaces and investigate how well the salient design elements in these mobile user interfaces meet the usability requirements of people aging with MS and an aging population. Usability testing was conducted in a controlled environment, CATEA's Usability Lab, and in participants' houses using the same equipment if they could not travel to CATEA.

3.1.3.1.1 Participants

Participants were recruited from the CATEA Consumer Network (CCN). To increase the reliability of results and the percentage of identified usability problems (Faulkner, 2003), a total number of 19 participants were recruited, which were divided into two groups of participants (i.e., individuals aging with MS and older adults). The inclusion criteria for the first group were that participants be of age 65 and older, and the inclusion criteria for the second group were that participants be of age 18 and older and that they were diagnosed with MS at least five years ago. The characteristics of the two groups of participants are presented in Table 20.

Table 20 – Characteristics of the two groups of participants

Participants	Female	Male	Age range (years)	Mean age (years)
Individuals aging with MS	9	0	33 - 67	51.11 ± 11.22
Older adults	6	4	65 - 77	68.90 ± 3.90

The background questionnaire was administered, and participants self-reported their number and types of functional limitations (Figure 6, Table 21).

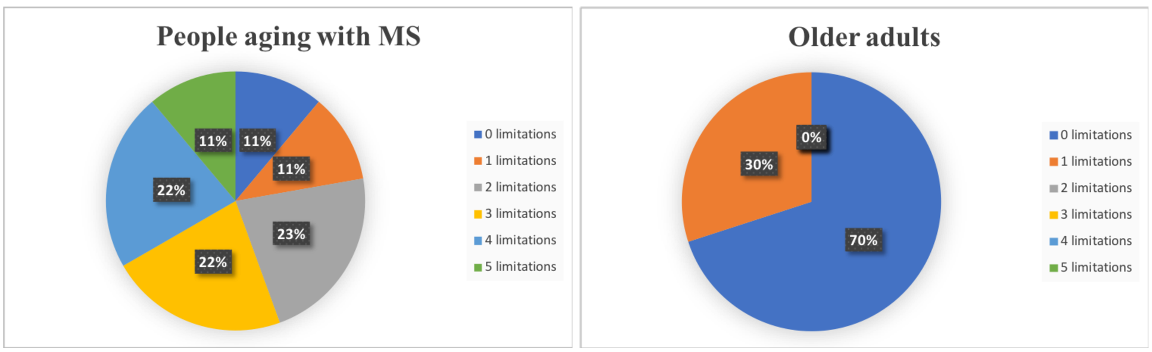


Figure 6 – Number of functional limitations in two groups of participants

Table 21 – Types of functional limitations in two groups of participants

Participants	Functional Limitations								
	Fatigue	Dexterity	Pain	Balance	Gait	Numbness	Cognition	Mobility	Tremor
Individuals aging with MS	1	3	1	1	5	1	3	3	1
Older adults	0	0	0	0	0	0	0	2	0

Table 21 – Types of functional limitations in two groups of participants (*Continued*)

Participants	Functional Limitations					
	Sensation of the left side of the body	Lower Extremity Weakness	Limited arm mobility	Foot drop	Hip problem	Vision
Individuals aging with MS	1	1	3	2	0	1
Older adults	0	0	0	0	1	0

3.1.3.1.1.1 Use of Mobile Health and MS-specific Apps

Participants self-reported use of mobile, mobile health, and MS-specific applications ranging from frequently (e.g., a few times a day), often (e.g., once a day), occasionally (e.g., once or twice a week), very infrequently (e.g., once a month), to never (Table 22).

Table 22 – Use of mobile, mobile health, and MS-specific applications in people with MS and older adults

	Participants	Frequently	Often	Occasionally	Very infrequently	Never
Use of mobile apps	People aging with MS	7	0	2	0	0
	Older adults	2	2	2	4	0
Use of mobile health apps	People aging with MS	0	1	2	4	2
	Older adults	1	0	1	4	4
Use of MS-specific mobile apps	People aging with MS	0	3	1	1	4

3.1.3.1.1.2 Computer and Touch Screen Experience

Participants self-reported their computer and touchscreen experience on a scale from 1 = none, 2 = novice, 3 = intermediate, 4 = advanced, to 5 = expert. The level of computer and touchscreen experience was presented in Table 23.

Table 23 – Computer and touchscreen experience in focus group participants

Participants	**Computer experience**		**Touchscreen experience**	
	Mean, M	**Standard Deviation, SD**	**Mean, M**	**Standard Deviation, SD**
People aging with MS	3.89	1.36	3.67	0.87
Older adults	3.10	0.57	3.1	0.99

I found no statistical difference between the self-reported computer and touchscreen experience in two groups of participants (t_1 (10) = 1.619, p_1 = 0.137; t_2 (17) = 1.336, p_2 = 0.199, respectively).

3.1.3.1.1.3 Accessibility Features

The participants reported the use of the accessibility features on their smartphones (Table 24).

Table 24 – Use of the accessibility features in the two groups of participants

Participants	Accessibility Features				
	Large text size or zoom	Voice-over	High contrast or inverted colors	Assistive touch	No accessibility features
People aging with MS	7	5	1	1	0
Older adults	6	1	0	0	0

3.1.3.1.2 Testing Devices and Mobile Applications

In this study, I used an iPhone 6 to test a more realistic everyday use of the three mobile applications. The iPhone 6 has Retina HD display that is 4.7 inches in size with a 16:9 resolution of 1334x750 (326 ppi). Two MS health and wellness self-management mobile applications, *My MS Manager* and *MS self*, and *iHealth*, an integrated mobile health app for the general population were chosen for this study (Figure 5).

3.1.3.1.3 Procedures

First, participants signed the informed consent form approved by the Georgia Tech IRB and the background questionnaire was administered. They self-reported their age, gender, number and types of functional limitations, and use of accessibility features on mobile devices, and rated their use of mobile apps, mHealth apps, MS-specific apps, computer and touchscreen experience.

Second, they performed three sets of tasks on three chosen mobile interfaces (*My MS Manager*, *MS self*, and *iHealth*) (Table 26). The order of the mobile applications was counterbalanced and randomly assigned to each participant. They were asked to complete each task and ask for help when they cannot find a solution to finish the task. Participants answered a questionnaire rating the UI elements and two interview questions identifying the barriers and facilitators to usability following the completion of each set of tasks. Usability study was video recorded using the GoPro Hero 3 cameras and lasted from 60 to 150 minutes. All participants were compensated $20.00 for their time and $5 for the travel to Georgia Tech.

All participants performed three sets of tasks on *My MS Manager*, *MS Self*, and *iHealth*. The tasks on *iHealth* were short and simple, and therefore the number of tasks for this app increased to seven tasks. The first four tasks on *My MS Manager* and *MS Self* were the same (Table 26). Task 1 (*My MS Manager* and *MS self*) asked participants to open a Journal, create a new entry, fill out the entry with the prescribed data, and make another entry with a different set of data. The second entry contained different data that require a slight change in navigation. Task 1 in *iHealth* asked them to find and open Goals and populate the entry with the prescribed data. Task 2 (*My MS Manager*) required participants to open two existing entries from the list. In *MS self*, they opened History from the Journal entry screen and from there opened two entries from the list. In *iHealth* task 2, they found and opened Reminder, created a new task and populated it with the prescribed data. Task 3 (*My MS Manager*) requested participants to open Charts, select a date range, filter chart data, and look up the two selected charts. In *MS self*, they selected a date range, filtered data, generated a report, and looked up the two reports. In *iHealth* task 3, they navigated the interface to measure their blood pressure using the BPM. Task 4 (*My MS Manager* and *MS self*) required them to open the function and skip it. In *iHealth* Task 4 they found and opened new manual entry and populated it with the prescribed data. In task 5 (*My MS Manager*) they opened Treatments, created a new entry, and filled out the entry with the prescribed data. Task 5 in *MS self* required them to Open Fact Cards and look up the Tips for Living Well. In *iHealth*, they found the BP results list, deleted the entry, and then decided to keep the entry. Task 6 (*iHealth*) asked them to find and look up BP trends and lists. In task 7 (*iHealth*) they found and opened My Diary, opened lunch, searched for the specific meal, selected it, opened activity, selected a specific one, and set up time for practice. UI elements used in each task for all three mobile health applications are listed in Table 25.

Table 25 – Design elements used in each task for *My MS Manager*, *MS Self*, and *iHealth*

Mobile Application	Tasks	Input Controls	Navigational Components	Information Components
My MS Manager	1. Create two Journal entries	Button, checkbox, toggle button, text field, picker, keyboard	Icon, navigation bar	Message box
	2. Look up two previous entries	Button	Navigation bar	
	3. Create Chart	Button, checkbox	Icon	Tool tips
	4. Skip My Exacerbations	Button	Icon, navigation bar	
	5. Add a Treatment	Button, picker, keyboard	Icon, navigation bar	Message box
MS Self	1. Create two Journal entries	Button, checkbox, text field, keyboard	Icon, navigation bar, panel	Confirmation box
	2. Look up two previous entries	Button	Icon, panel	
	3. Create Report	Button, checkbox	Icon, collapsible set	
	4. Skip Achievements	Button	Icon, navigation bar	
	5. Look up Tips for Living Well	Button	Icon	
iHealth	1. Add Goals	Button, numeric keyboard		
	2. Add Reminders	Button, picker, checkbox	Icon, navigation bar	Message box
	3. Measure blood pressure (BP)	Button		
	4. Create manual BP entry	Button, picker		
	5. Delete entry	Button, checkbox	Navigation bar	Message box
	6. Look up BP trends and lists	Button	Icon	
	7. Use My Diary	Button, picker	Search, collapsible set	

3.1.3.1.4 Outcome Measures

I measured the task completion rates (i.e., the percentage of completed tasks), the user success rate (i.e., the percentage of tasks completed correctly without asking for help), and number and frequency of help requests. Additionally, I identified types of unique help requests, and I reported ratings of design elements and the barriers and facilitators to usability.

3.1.3.1.4.1 Effectiveness

The task completion rates (i.e., the percentage of completed tasks) and the user success rate (i.e., the percentage of tasks completed correctly without asking for help) were recorded. Participants were asked to complete each task and ask for help when they could not find the solution to finish the task. Counting help requests was used as a filter for errors, allowing only important errors to pass through. The number of times participants requested help was recorded, and the frequency of help requests was reported (i.e., the number of help requests divided by the number of participants per group). I described each help request that occurred during the testing and recorded it as a specific problem. The help requests were coded based on their general nature (e.g., navigation, instructions, selection, etc.). Based on the number and frequency of these types of help requests, the weak points (i.e., barriers) of the interface were prioritized. The frequency of help requests by type of functional ability, depending on the ability required to perform the step, was reported as well.

The category of **cognitive issues** included the problems participants had with the Instructions, Navigation, Location, Picker, Button active area, Selection, and Mistakes. Leveling the hand while using the blood pressure monitor (BPM) in *iHealth* was coded as Instructions since the interface provided the directions for measuring the blood pressure. Navigation issues included the following: adding the new task, going back and forth, skipping, deleting, generating the report, and updating the task. Location problems related to finding the specific features or sub-features, such as Goals and Reminder in *iHealth*, Achievements and Report in *MS Self*, Journal in both *MS Self* and *My MS Manager*, and similar. Problems with the use of the picker were coded as Picker. Adding a comment in *MS Self* and *My MS Manager*, pressing + to navigate, tapping to add, tapping >+ part of the button to navigate were coded as Button active area. Selecting mood and symptoms in *MS Self*, exacerbations and mood in *My MS Manager*, day rating in *My MS Manager*, charts in *MS Self*, disability level in *My MS Manager*, every day in *iHealth*, 90 days within the

Chart feature in *MS Self*, as well as deselect any of the options were a part of the Selection problems. When participants did not enter a required date, I coded that as a mistake. Problems with the touchscreen, tapping twice, unresponsive screen, and button size were coded as **dexterity issues**. **Visual problems** included issues with the contrast, which was mostly due to the very low contrast on "Done" button in *iHealth* app (Table 26).

Table 26 – Categorization of the help requests based on their general nature and the ability required to perform the step

Ability	Nature of the problem	Specific Problem
Cognitive	Unclear instructions	Leveling the hand (BPM)
	Difficulty navigating between the pages	Add new task, go back and forth, skip, delete, generate report, update
	Confusion over where to go to enter new data	Find Goals, Achievements, Reminder, Report, Journal, etc.
	Use of picker	Using the picker
	Unclear active area of the button	Add a comment, Press +, Tap to add, > + buttons
	Issues with selection	Select every day, Select 90 days (Chart)
	Mistakes	Not entering required date
Dexterity	Touchscreen issues	Tapping twice, unresponsive screen, button size
Visual	Low contrast	Done button
	Small font size	Small font size

3.1.3.1.4.2 Barriers and Facilitators

Fourteen design elements were rated by the participants using the Likert scale from 1 = strongly disagree, to 5 = strongly agree. Two open-ended interview questions were used to further identify barriers and facilitators. All the recorded video files (19 participants x 3 mobile health interfaces = 57 files) were used to confirm the nature of the specific problems participants encountered.

3.1.3.2 Results

All participants (n = 19) completed all three trials (3 mobile health interface designs x 19 participants = 57 completed trials). The total study time lasted from 1 to 2.5 hours.

3.1.3.2.1 Effectiveness

Task completion rates for all participants and all tasks were 12.07%. Out of a total number of tasks (19 participants x 17 tasks = 323 tasks), 39 tasks (12.07%) were completed successfully without asking for help (i.e., the user success rate). 284 tasks (87.93%) required at least one help request (Table 27). 1 participant with MS did not ask for help while performing all the tasks on all 3 apps, 1 participant with MS and 1 older adult did not request help while performing all the tasks on *MS Self*, and 1 older adult did not ask for help while completing the tasks on *My MS Manager* and *iHealth* apps.

Out of a total of 339 help requests, people with MS asked 112, and older adults 227 times for help. Help requests related to cognitive abilities accounted for a majority of problems, with 107 being asked by people with MS and 217 asked by older adults. There was only 1 help request by people with MS-related to dexterity problems, and 10 by older adults. Visual issues accounted for 4 help requests by people with MS, and none by older adults. Among the cognitive issues, the biggest number of help requests came from the problems with navigation and finding the interface features and sub-features for both groups of participants (Table 27). The frequency of help requests allows for a comparison between the two groups of participants.

Overall, the largest number and frequency of help requests come from the problems with the navigation and locating the pages for both groups of participants.

Table 27 – The number and frequency of help requests by the nature of the problem and the ability required to perform the step for people with MS and older adults

Group of participants	Nature of the problem	Number and Frequency of Help Requests	Ability	Number and Frequency of Help Requests	Total Number and Frequency of Help Requests
People with MS **(9 participants)**	Navigation	n=52 F=5.78	Cognitive	n=107 F=11.89	n=112 F=12.44
	Location	n=41 F=4.56			
	Instructions	n=6 F=0.67			
	Button active area	n=4 F=0.44			
	Picker	n=2 F=0.22			
	Selection	n=1 F=0.11			
	Mistake	n=1 F=0.11			
	Contrast	n=4 F=0.44	Visual	n=4 F=0.44	
	Touchscreen	n=1 F=0.11	Dexterity	n=1 F=0.11	
Older Adults **(10 participants)**	Location	n=95 F=9.50	Cognitive	n=217 F=21.70	n=227 F=22.70
	Navigation	n=90 F=9.00			
	Button active area	n=9 F=0.90			
	Selection	n=9 F=0.90			
	Picker	n=8 F=0.80			
	Instructions	n=3 F=0.30			
	Mistake	n=3 F=0.30			
	Touchscreen	n=10 F=1.00	Dexterity	10 F=1.00	
	Contrast	n=0 F=0	Visual	0 F=0	

3.1.3.2.2 Barriers and Facilitators

Fourteen design criteria were rated on a scale from 1 = strongly disagree, to 5 = strongly agree. Value 3 was used when the participants responded with n/a for a specific rating. The mean rating was reported for all three apps and both user groups with the mean differences between the app ratings (Table 28 and Table 29).

Table 28 – Mean ratings (with standard deviations) of the design criteria for all three apps by individuals with MS

Design Criteria	**Mean Ratings (Standard Deviations)**			***T* value and *P* value**		
	My MS Manager	**MS Self**	**iHealth**	**My MS Manager and MS Self**	**MS Self and iHealth**	**My MS Manager and iHealth**
Mobile app easy to use	3.33 (1.00)	4.33 (1.00)	3.00 (1.12)	4.399 **0.002	3.776 **0.005	4.243 **0.003
Touch buttons, swipe, scroll easy to use	4.22 (1.09)	4.11 (1.05)	4.33 (0.87)	1.000 0.347	2.530 *0.035	2.000 0.081
Navigation easy to use	3.44 (1.33)	4.00 (1.12)	3.00 (1.00)	3.773 **0.005	3.355 *0.010	2.309 0.050
Main menu easy to find	4.00 (1.12)	4.11 (0.93)	3.00 (1.12)	4.243 **0.003	3.592 **0.007	3.464 **0.009
Skipping content easy to do	4.11 (1.05)	4.44 (0.53)	4.22 (0.67)	2.401 *0.043	1.835 0.104	2.401 *0.043
Icons easy to recognize	4.33 (0.71)	4.44 (1.01)	3.89 (1.27)	2.000 0.081	1.793 0.111	1.512 0.169
Instructions easy to understand	3.78 (1.09)	3.89 (1.05)	3.67 (1.12)	2.800 *0.023	4.000 **0.004	6.000 ***< 0.001
Easy to understand when the task was completed	4.00 (1.32)	4.33 (0.87)	4.00 (0.87)	2.683 *0.028	3.500 **0.008	3.162 *0.013
Color contrast high enough	3.89 (1.45)	4.22 (1.09)	4.11 (0.93)	1.250 0.247	3.162 *0.013	2.000 0.081
Text size big enough	3.89 (1.27)	3.78 (1.64)	4.00 (1.00)	2.294 0.051	2.000 0.081	2.401 *0.043
The prompt messages easy to understand	3.89 (0.60)	4.33 (0.87)	3.44 (1.01)	4.264 **0.003	2.874 *0.021	3.411 **0.009
Single tap easy to use	3.89 (0.93)	4.56 (0.53)	4.33 (0.71)	1.789 0.111	2.530 *0.035	2.530 *0.035
Mobile app physically easy to use	4.22 (0.67)	4.44 (1.01)	3.89 (1.27)	2.309 0.050	2.135 0.65	3.000 *0.017
Touch buttons big enough	3.78 (1.09)	4.22 (1.09)	4.00 (1.22)	2.000 0.081	2.530 *0.035	1.789 0.111

*Significant level $p < 0.05$

**Significant level $p < 0.01$

***Significant level $p < 0.001$

Table 29 – Mean ratings (with standard deviations) of the design criteria for all three apps by older adults

Design Criteria	**Mean Ratings (Standard Deviations)**			***T* value and *P* value**		
	My MS Manager	**MS Self**	**iHealth**	**My MS Manager and MS Self**	**MS Self and iHealth**	**My MS Manager and iHealth**
Mobile app easy to use	3.00 (0.94)	3.80 (0.92)	3.20 (1.14)	3.207 *0.011	2.714 *0.024	4.000 **0.003
Touch buttons, swipe, scroll easy to use	3.44 (1.17)	4.10 (0.74)	3.20 (0.92)	2.333 *0.045	3.674 **0.005	6.091 ***<0.001
Navigation easy to use	3.00 (1.41)	3.50 (1.27)	3.00 (1.05)	2.236 0.052	2.906 *0.017	3.354 **0.008
Main menu easy to find	3.80 (1.32)	4.00 (1.05)	3.20 (1.48)	2.450 *0.037	2.121 0.063	2.535 *0.032
Skipping content easy to do	3.40 (1.35)	3.70 (0.95)	3.30 (0.82)	3.000 *0.015	2.714 *0.024	3.857 **0.004
Icons easy to recognize	3.80 (1.03)	4.00 (1.05)	3.90 (0.74)	2.714 *0.024	3.857 **0.004	3.857 **0.004
Instructions easy to understand	2.90 (0.74)	3.10 (1.37)	2.80 (1.14)	2.689 *0.025	2.090 0.066	2.236 0.052
Easy to understand when the task was completed	3.80 (0.92)	4.22 (0.79)	4.00 (0.67)	1.500 0.168	2.450 *0.037	2.450 *0.037
Color contrast high enough	3.40 (1.17)	4.22 (1.03)	3.70 (1.16)	2.714 *0.024	1.809 0.104	2.862 *0.019
Text size big enough	3.50 (1.43)	3.70 (1.06)	3.30 (1.42)	3.873 **0.004	4.000 **0.003	2.753 *0.022
The prompt messages easy to understand	2.90 (1.20)	3.10 (1.10)	3.00 (1.15)	3.207 *0.011	6.091 ***<0.001	3.973 **0.003
Single tap easy to use	3.60 (1.07)	4.10 (0.88)	3.70 (1.16)	3.280 *0.010	2.450 *0.037	3.280 *0.010
Mobile app physically easy to use	3.40 (1.26)	4.20 (0.79)	3.60 (1.17)	2.450 *0.037	1.964 0.081	2.714 *0.024
Touch buttons big enough	3.60 (1.17)	3.90 (1.20)	4.10 (0.88)	1.406 0.193	1.809 0.104	2.689 *0.025

*Significant level $p < 0.05$

**Significant level $p < 0.01$

***Significant level $p < 0.001$

I used paired t-test to analyze the significance of the differences of ratings within a group and between the apps. Additionally, I used t-test on independent means (i.e., two-sample t-test) to assess the significance of the differences in ratings between older adults and people aging with MS (De Winter & Dodou, 2010). Researchers (De Winter & Dodou, 2010) compared the capabilities of the two-sample t-test and the Mann-Whitney test to analyze five-point Likert items for two groups of participants, and they showed that for all pairs of distributions the Type I (i.e., false positive) error rates are very close to the target amount. Therefore, if either analysis is used and the results are statistically significant, there is not too much chance for the Type I error. The results proved that for most pairs of distributions, the difference between the statistical power of the two tests is unimportant. Thus, if there is a significant difference at the population level, either analysis is equally likely to detect it.

Overall, *MS self* had the highest ratings in both user groups, and seniors rated all three apps lower than the individuals with MS did. Specifically, *MS self* was rated higher than *My MS Manager* and *iHealth* by individuals aging with MS for most of the design elements: mobile app easy to use (t_1 (8) = 4.399, p_1 = 0.002; t_2 (8) = 3.776, p_2 = 0.005, respectively), navigation easy to use (t_1 (8) = 3.773, p_1 = 0.005; t_2 (8) = 3.355, p_2 = 0.010, respectively), main menu easy to find (t_1 (8) = 4.243, p_1 = 0.003; t_2 (8) = 3.592, p_2 = 0.007, respectively), instructions easy to understand (t_1 (8) = 2.800, p_1 = 0.023; t_2 (8) = 4.000, p_2 = 0.004, respectively), easy to understand when the task was completed (t_1 (8) = 2.683, p_1 = 0.028; t_2 (8) = 3.500, p_2 = 0.008, respectively), and the prompt message was easy to understand (t_1 (8) = 4.264, p_1 = 0.003; t_2 (8) = 2.874, p_2 = 0.021, respectively).

Easy skipping of content was rated significantly higher for *MS self* than for *My MS Manager*, but there was no significant difference between the ratings for *MS self* and *iHealth* by individuals with MS (t_1 (8) = 2.401, p_1 = 0.043; t_2 (8) = 1.835, p_2 = 0.104, respectively). There was no significant difference between the ratings of *MS self* compared to those of *My MS Manager* and *iHealth* for recognizability of icons (t_1 (8) = 2.000, p_1 =

0.081; t_2 (8) = 1.793, p_2 = 0.111, respectively). There was no significant difference between the ratings of the color contrast for *MS self* and *My MS Manager,* but it was rated higher for *MS self* than for *iHealth* (t_1 (8) = 1.250, p_1 = 0.247; t_2 (8) = 3.162, p_2 = 0.013, respectively). There was no significant difference between the ratings for *MS self* and the other two app for large enough text size (t_1 (8) = 2.294, p_1 = 0.051; t_2 (8) = 2.000, p_2 = 0.081, respectively). There was no significant difference between the ratings of the ease of use of single tap for *MS self* and *My MS Manager,* but it was rated higher for *MS self* than for *iHealth* (t_1 (8) = 1.789, p_1 = 0.111; t_2 (8) = 2.530, p_2 = 0.035, respectively). There was no significant difference between the ratings for *MS self* and the other two app for the physical ease of use (t_1 (8) = 2.309, p_1 = 0.050; t_2 (8) = 2.135, p_2 = 0.065, respectively). There was no significant difference between the ratings of the large enough touch buttons for *MS self* and *My MS Manager,* but it was rated higher for *MS self* than for *iHealth* (t_1 (8) = 2.000, p_1 = 0.081; t_2 (8) = 2.530, p_2 = 0.035, respectively).

There was no significant difference in the ratings of the ease of use of the touch buttons, swipe, and scroll between *MS self* and *My MS Manager,* and *MS self* was rated significantly lower than *iHealth* by the individuals aging with MS (t_1 (8) = 1.000, p_1 = 0.347; t_2 (8) = 2.530, p_2 = 0.035, respectively).

Among the older adults, *MS self* was rated higher than *My MS Manager* and *iHealth* by individuals aging with MS for most of the design elements: mobile app easy to use (t_1 (9) = 3.207, p_1 = 0.011; t_2 (9) = 2.714, p_2 = 0.024, respectively), the ease of use of the touch buttons, swipe, and scroll (t_1 (9) = 2.333, p_1 = 0.045; t_2 (9) = 3.674, p_2 = 0.005, respectively), skipping content easy to do (t_1 (9) = 3.000, p_1 = 0.015; t_2 (9) = 2.714, p_2 = 0.024, respectively), icons easy to recognize (t_1 (9) = 2.714, p_1 = 0.024; t_2 (9) = 3.857, p_2 = 0.004, respectively), large enough text size (t_1 (9) = 3.873, p_1 = 0.004; t_2 (9) = 4.000, p_2 = 0.003, respectively), the prompt message easy to understand (t_1 (9) = 3.207, p_1 = 0.011; t_2 (9) = 6.091, p_2 < 0.001, respectively), and single tap easy to use (t_1 (9) = 3.280, p_1 = 0.010; t_2 (9) = 2.450, p_2 = 0.037, respectively).

There was no significant difference in the ratings between *MS self* and *My MS Manager* for ease of navigation, and *MS self* was rated significantly higher than *iHealth* by the individuals aging with MS (t_1 (9) = 2.236, p_1 = 0.052; t_2 (9) = 2.906, p_2 = 0.017, respectively). *MS self* was rated significantly higher than *My MS Manager* for ease of finding the main menu, and there was no significant difference between *MS self* and *iHealth* (t_1 (9) = 2.450, p_1 = 0.037; t_2 (9) = 2.121, p_2 = 0.063, respectively). *MS self* was rated significantly higher than *My MS Manager* for ease of understanding the instructions, and there was no significant difference between *MS self* and *iHealth* (t_1 (9) = 2.689, p_1 = 0.025; t_2 (9) = 2.090, p_2 = 0.066, respectively). There was no significant difference in the ratings of between *MS self* and *My MS Manager* for ease of understanding when the task is completed, and *MS self* was rated significantly higher than *iHealth* by the individuals aging with MS (t_1 (9) = 1.500, p_1 = 0.168; t_2 (9) = 2.450, p_2 = 0.037, respectively). *MS self* was rated significantly higher than *My MS Manager* for high enough color contrast, and there was no significant difference between *MS self* and *iHealth* (t_1 (9) = 2.714, p_1 = 0.024; t_2 (9) = 1.809, p_2 = 0.104, respectively). *MS self* was rated significantly higher than *My MS Manager* for physical ease of use, and there was no significant difference between *MS self* and *iHealth* (t_1 (9) = 2.714, p_1 = 0.024; t_2 (9) = 1.809, p_2 = 0.104, respectively). There was no significant difference between the ratings for *MS self* and the other two app for the large enough size of the touch buttons (t_1 (9) = 1.406, p_1 = 0.193; t_2 (9) = 1.809, p_2 = 0.104, respectively).

Overall, the differences in mean ratings between two groups of participants were not significant (Table 30), except in a case of ease of use of touch buttons, swipe, scroll and for ease of skipping the content for *iHealth*, which people with MS rated significantly higher than older adults did (t (17) = 2.767, p = 0.014; t (17) = 2.694, p = 0.016, respectively). People with MS rated ease of understanding the prompt message significantly higher than older adults did for *My MS Manager* and *MS self* (t (14) = 2.309, p = 0.038; t (17) = 2.728, p = 0.015, respectively).

Table 30 – Mean differences in ratings (with mean ratings and standard deviations) of the design criteria for all three apps between people aging with MS and older adults

Design Criteria	**Mean Ratings (Standard Deviations) and Mean Differences: *T* value (*P* value)**					
	My MS Manager		**MS Self**		**iHealth**	
	People with MS	**Older Adults**	**People with MS**	**Older Adults**	**People with MS**	**Older Adults**
Mobile app easy to use	3.33 (1.00)	3.00 (0.94)	4.33 (1.00)	3.80 (0.92)	3.00 (1.12)	3.20 (1.14)
	t (17) = 0.745, *p* = 0.467		*t* (16) = 1.206, *p* = 0.245		*t* (17) = 0.386, *p* = 0.705	
Touch buttons, swipe, scroll easy to use	4.22 (1.09)	3.44 (1.17)	4.11 (1.05)	4.10 (0.74)	4.33 (0.87)	3.20 (0.92)
	t (17) = 1.495, *p* = 0.154		*t* (14) = 0.026, *p* = 0.979		*t* (17) = 2.767, **p* = 0.014	
Navigation easy to use	3.44 (1.33)	3.00 (1.41)	4.00 (1.12)	3.50 (1.27)	3.00 (1.00)	3.00 (1.05)
	t (17) = 0.705, *p* = 0.491		*t* (17) = 0.913, *p* = 0.375		*t* (17) = 0.000, *p* = 1.000	
Main menu easy to find	4.00 (1.12)	3.80 (1.32)	4.11 (0.93)	4.00 (1.05)	3.00 (1.12)	3.20 (1.48)
	t (17) = 0.358, *p* = 0.725		*t* (17) = 0.244, *p* = 0.810		*t* (17) = 0.335, *p* = 0.742	
Skipping content easy to do	4.11 (1.05)	3.40 (1.35)	4.44 (0.53)	3.70 (0.95)	4.22 (0.67)	3.30 (0.82)
	t (17) = 1.286, *p* = 0.217		*t* (14) = 2.141, *p* = 0.050		*t* (17) = 2.694, **p* = 0.016	
Icons easy to recognize	4.33 (0.71)	3.80 (1.03)	4.44 (1.01)	4.00 (1.05)	3.89 (1.27)	3.90 (0.74)
	t (16) = 1.324, *p* = 0.205		*t* (17) = 0.936, *p* = 0.363		*t* (13) = 0.023, *p* = 0.982	
Instructions easy to understand	3.78 (1.09)	2.90 (0.74)	3.89 (1.05)	3.10 (1.37)	3.67 (1.12)	2.80 (1.14)
	t (14) = 2.029, *p* = 0.063		*t* (17) = 1.414, *p* = 0.177		*t* (17) = 1.675, *p* = 0.113	
Easy to understand task completion	4.00 (1.32)	3.80 (0.92)	4.33 (0.87)	4.22 (0.79)	4.00 (0.87)	4.00 (0.67)
	t (14) = 0.379, *p* = 0.711		*t* (16) = 0.291, *p* = 0.775		*t* (15) = 0.000, *p* = 1.000	
Color contrast high enough	3.89 (1.45)	3.40 (1.17)	4.22 (1.09)	4.22 (1.03)	4.11 (0.93)	3.70 (1.16)
	t (15) = 0.801, *p* = 0.436		*t* (17) = 0.000, *p* = 1.000		*t* (17) = 0.857, *p* = 0.404	
Text size big enough	3.89 (1.27)	3.50 (1.43)	3.78 (1.64)	3.70 (1.06)	4.00 (1.00)	3.30 (1.42)
	t (17) = 0.627, *p* = 0.539		*t* (13) = 0.121, *p* = 0.905		*t* (16) = 1.253, *p* = 0.228	
The prompt messages easy to understand	3.89 (0.60)	2.90 (1.20)	4.33 (0.87)	3.10 (1.10)	3.44 (1.01)	3.00 (1.15)
	t (14) = 2.309, **p* = 0.038		*t* (17) = 2.728, **p* = 0.015		*t* (17) = 0.893, *p* = 0.385	
Single tap easy to use	3.89 (0.93)	3.60 (1.07)	4.56 (0.53)	4.10 (0.88)	4.33 (0.71)	3.70 (1.16)
	t (17) = 0.629, *p* = 0.539		*t* (15) = 1.389, *p* = 0.186		*t* (15) = 1.453, *p* = 0.167	
Mobile app physically easy to use	4.22 (0.67)	3.40 (1.26)	4.44 (1.01)	4.20 (0.79)	3.89 (1.27)	3.60 (1.17)
	t (14) = 1.797, *p* = 0.096		*t* (15) = 0.582, *p* = 0.569		*t* (16) = 0.513, *p* = 0.615	
Touch buttons big enough	3.78 (1.09)	3.60 (1.17)	4.22 (1.09)	3.90 (1.20)	4.00 (1.22)	4.10 (0.88)
	t (17) = 0.342, *p* = 0.737		*t* (17) = 0.613, *p* = 0.548		*t* (14) = 0.203, *p* = 0.842	

*Significant level p < 0.05

**Significant level p < 0.01

***Significant level p < 0.001

Main barriers identified by both user groups were instructions, text size, and prompt messages. In addition, older adults identified the size of touch buttons, physical ease of use, single tap, color contrast, skipping content, icons, navigation, finding main menu, ease of use, touch buttons, swiping, and scrolling as barriers to usability.

3.1.3.2.2.1 Interview Results

Two interview questions confirmed the previous findings and identified additional barriers and facilitators to usability for the two groups of participants (Table 31 and Table 32). Both groups of participants identified navigation, especially navigating back to a homepage, as a problem on all three apps. Both user groups had issues with finding the specific pages on *iHealth* and people with MS encountered this problem on *My MS Manager*. It was not evident when they completed the task, they needed additional instructions for using the apps, it was not clear if they saved an entry, and font and button sizes were too small for most of the users on all three apps. Older adults had problems with color contrast on all three interfaces, and issues with scrolling on *iHealth* and *My MS Manager*. Among the facilitators identified, the found emoticons on *MS Self* to be usable, color contrast on *My MS Manager* was good enough, *MS Self* and *My MS Manager* were found to be simple and intuitive to some users and use of blood pressure cuff on *iHealth* was found to be very useful. In addition, among the barriers and facilitators identified, I found some design elements that were present in both categories.

Moreover, there were some inconsistencies between the ratings of the design elements and the answers to the interview questions participants made. For example, both user groups rated highly how easy it was to understand when the task was completed, but when asked to identify the barriers to usability, individuals with MS reported task completion for all three apps, and seniors reported it for *My MS Manager*. I relied more on the answers to the interview questions because of the detailed explanations from the participants and the nature of the open-ended questions.

Table 31 – Barriers and facilitators to usability for individuals aging with MS

Usability Problems		My MS Manager	MS Self	iHealth
Barriers	**Navigation**	Difficulty navigating between the screens; Confusion over where to go to enter new data; Going back to home page and previous pages; Lack of understanding of the prompt messages	Difficulty navigating between the screens; Confusion over where to go to enter new data; Going back to home page; Lack of consistency	Difficulty navigating between the screens; Confusion over where to go to enter new data; Lack of intuitiveness; Cumbersome to use; Too many steps required
	Page design	Unclear page layout	Confusing Home page	Unclear page layout; Lack of horizontal orientation
	Button design	Small size of the buttons; Small spacing between the buttons	Hamburger button is hard to use	Done button on a keyboard is too small and has low contrast
	Confirmation of an action	Unclear task completion	Unclear task completion	Unclear task completion
	Data entry	Unclear process for saving data		
	Page information	Lack of instructions; Too much information		Lack of instructions
	Physical navigation	Issues with tapping		
	Visualization			Color scheme is too soft
Facilitators	**Navigation**	Intuitiveness; Ease of use	Intuitiveness; Good interface design; Clear prompt messages	
	Page design	Home page design	Good design of the secondary pages; Good page layout; Good design and use of Tips, Achievements pages	Good page design;
	Button design	Good design of home page icons; Large enough button size on home page	Easy to read; Good design and use of emoticons; Good design and use of green checkmark icon; Large enough font size; Presence of both icons and text	Good design of the buttons; Good design and use of icons
	Physical navigation	Easy swiping	Easy swiping	Easy swiping; Easy scrolling
	Visualization	Good color contrast on homepage; Good color scheme	Good color scheme	
	Functionality			Use of the Bluetooth enabled blood pressure cuff

Table 32 – Barriers and facilitators to usability for older adults

Usability Problems		My MS Manager	MS Self	iHealth
Barriers	**Navigation**	Difficulty navigating between the screens; Confusion over where to go to enter new data; Going back to home page; Complexity; Lack of understanding of the prompt messages	Difficulty navigating between the screens; Confusion over where to go to enter new data; Lack of consistency; Lack of intuitiveness	Difficulty navigating between the screens; Confusion over where to go to enter new data; Confusing use of Settings to enter data; Lack of consistency; Lack of intuitiveness; Hard to learn; Lack of prompt messages
	Page design		Confusing Home page; Small charts	Confusing Home page
	Button design	Small font size; Small size of the buttons; Done button is too small with low contrast (keyboard); Design and use of icons	Small font size; Small font size (charts); Small size of the buttons; Use of thin font; Design and use of icons	Small font size; Small size of the buttons; Done button is too small with low contrast (keyboard);
	Confirmation of an action	Unclear task completion		
	Data entry and editing	Unclear process for saving data		Unclear process for saving and deleting data
	Page information	Lack of instructions; Lack of help	Lack of instructions	Lack of instructions; Lack of help; Lack of directions
	Physical navigation	Issues with tapping; Issues with scrolling		Issues with scrolling
	Visualization	Low color contrast	Low color contrast	Low color contrast; Poor color scheme
Facilitators	**Navigation**	Simple design and navigation	Simple design and navigation; Ease of use; Good interface design	
	Page design	Home page design	Design of the Journal pages	
	Button design	Good design of Done button	Large enough font size	
	Physical navigation		Easy swiping	Easy scrolling
	Confirmation of an action	Clear task completion		
	Page information		Good design of Report instructions	
	Visualization		Good color scheme	
	Functionality			Use of Bluetooth enabled blood pressure cuff

3.1.3.3 Design Recommendations

As individuals with MS age, they will experience the usability problems with mobile user interfaces that an aging population faces in addition to the issues they already have due to this chronic condition. Therefore, I identified the barriers and facilitators to usability that both groups of participants face, to develop recommendations for the design of mobile applications for individuals aging with MS.

Based on the frequency of help requests, the design elements ratings, and the interview questions, I summarized and prioritized the barriers and facilitators for both user groups, and drew the following recommendations for the design of mobile health and wellness applications for individuals aging with MS:

1. Navigation needs to be clear, intuitive, easy to understand, and consistent.

Participants found hard to go back and forth from page to page because the way to navigate to different pages was not consistent (e.g., slide, hamburger menu, button, etc. were used randomly). One participant complained about the lack of next and back buttons. Several participants mentioned the lack of directions, instructions, and help to assist users with the navigation to specific pages within the interface and especially the homepage. Almost all participants had problems with the navigation back to the homepage. Fisk, Rogers, Charness, Czaja, & Sharit (2009) recommended that navigation assistance (e.g. help, review buttons) should be provided for understanding how to navigate to specific points in the system. This includes navigation to not only the homepage but any relevant page. Moreover, seamless use should be provided to users with a back button, next button, and similar. Be consistent with the ways of the navigation from page to page. Provide more than one way to go to different pages while keeping the consistency.

2. Locating pages needs to be easy and intuitive.

Many participants had problems with finding certain pages within the interface, especially in *iHealth* app. They had problems finding where to record all the entries and where to find the blood pressure monitor feature. Many participants had issues with finding the homepage from any other page. The researchers (Fisk et al., 2009) recommend organizing information within natural or consistent groupings (e.g. group related information and have most frequent operations highest on the menu structure) to allow a user to easily find needed piece of information and related page. Indicate clearly where the user currently is at any point in time. The sequences of actions should be available and visible in the interface, and the user should not be expected to remember them. Make it clear how to navigate to all main point of the interface from the homepage, and how to go back to homepage from any other page.

3. Task completion needs to be evident and bold so that users know they have accomplished their tasks and they can continue with the subsequent activities.

Most of the participants had problems with the task completion because they did not get any feedback that their entries have been saved and that they have completed the entry successfully. Some participants even suggested that they should get a message saying "Saved" or similar. Users should be given the satisfaction of accomplishment and completion, a sense of relief, and an indicator to prepare for the next group of actions, no matter where they are (Shneiderman, 1986). After users save any data, provide them with the information that their records have been saved and secured.

4. Provide specific and clear instructions for every step of the actions.

Most of the participants had problems with the lack of instructions during their navigation and use of the interface. They wanted instructions that user can refer to when using the mobile applications. Some participants had problems with the existing instructions and wanted simplified directions with the use of icons, and instructions that are more evident. Researchers (Fisk et al., 2009) found that technical language used in instructions and help systems might be difficult for older adults as their educational attainment levels may be lower than that of younger adults. Reading level of text material needs to be kept at grade 10 or below. Provide clear and understandable instructions for every task that can be completed and allow users to disable these instructions.

5. Font, buttons, and icons size (screen characters and targets) should be large enough to be usable by the end-users.

Screen characters and targets should be conspicuous and accessible (e.g., font size should be 12-point and higher, icons should be large enough to select easily) (Fisk et al., 2009). Use at least 12-point x-height serif or sans serif fonts (e.g., Arial, Helvetica, Times Roman), preferably 14-point and bigger (L. Kascak, Rebola, et al., 2013b; L. Kascak, Rébola, et al., 2013). Avoid cursive and decorative fonts and use of all uppercase letters since it slows down reading. In mixed-case situations, uppercase text attracts more attention than lowercase ones. Buttons on the mobile touchscreen interfaces should be at least 9.6 millimeters diagonally (e.g., 44 x 44 pixels on iPad) (Parhi, Karlson, & Bederson, 2006).

6. Color contrast needs to be very high to allow for ease of use and legibility of information.

Many participants, especially older adults encountered problems with the color contrast, which was not high enough on some pages and when they had to select "Done" button on *iHealth* app. Researchers (Fisk et al., 2009) suggest providing at least 50:1 contrast (e.g. black text on white background). Make sure that color discriminations can be made easily by signaling important information using short wavelength (blue-violet-green) contrasts, using black on white or white on black text, avoiding colored and watermarked backgrounds for display of text (Fisk et al., 2009). The contrast ratio of 4.5:1, and preferably contrast ratio of 7:1 should be used, based on the WCAG 2.0 recommendations.

7. Avoid use of scrolling and picker.

Many participants experienced problems with scrolling, and especially with the picker. The majority of older adults could not understand how to use the picker, had problems to select with it and made similar mistakes from one picker to the other one. Scrolling text should be avoided because it is difficult to process (Fisk et al., 2009). If necessary to use, use slow scrolling rate. Avoid use of the picker. Replace it with the keyboard with large keypads.

3.1.3.4 Discussion

Cognitive, vision, and motor performance declines with age. The results of the study implied that seniors performed worse than individuals aging with MS. Although, only three older adults self-reported one functional limitation each, and people with MS self-reported total of twenty-seven functional limitations, the frequency of help requests in seniors was almost twice as great as the one in people aging with MS. This might be due to the differences in tech-savviness, although the self-reported computer and touchscreen experience were not significantly different (t_1 (10) = 1.619, p_1 = 0.137; t_2 (17) = 1.336, p_2 = 0.199, respectively). Another important finding was that both user groups of participants had the same or similar usability problems with the three mHealth apps (i.e., the identified usability problem categories were the same across two groups). Additionally, the main usability problems identified in this study were the issues with the navigation and finding certain pages for both groups of participants. Thus, the main recommendation is to make mobile applications more usable by simplifying its design and navigation and considering this a crucial factor when designing and developing mobile apps for older adults and people aging with MS.

In addition, I provided a set of evidence-based design recommendations to assist with the future development of mHealth interfaces for older adults, including people aging with disabilities. The navigation, locating the Home page and other pages within the interface, task completion, instructions, appropriate size of the fonts, buttons, and icons, high color contrast, and avoiding the use of scrolling and the picker represent the most important design elements that need to be considered for the development of mobile interfaces for population of people aging with MS. The recommendations represent the most important design elements that need to be considered for the development of mobile interfaces for an aging population and present the main considerations when designing for this specific population.

3.2 Refinement of the UDMIG to Include People Aging with Disabilities

With aging, the primary health condition (e.g., MS, cerebral palsy, or spinal cord injury) in these individuals becomes a risk factor the development of secondary health conditions that can cause additional impairments, activity limitations, or participation restrictions (Jette and Field, 2007). UDMIG v.2.0 failed to include the people aging with disabilities. Whereas data indicate that this is a growing population of potential users (G. F. Anderson, 2010; Sheets, 2005), the guidelines did not address the types of impairments and comorbidities experienced by these individuals. Based on the results of the previously reported study (Ljilja Ruzic & Sanford, 2017) and the design recommendations, I refined the UDMIG v.2.0 to include individuals aging with disabilities. The resulting UDMIG v. 2.1 (Appendix B) were prioritized into the eight essential guidelines and the remaining advisory guidelines. Among these eight essential design guidelines, six refer to the interface structure and two to the design elements. In addition, Same Means of Use guideline was added as the ninth mandatory guideline because it is the only UD principle that is essential to inclusivity and participation (Table 33). These first nine design guidelines (i.e., the first two design elements guidelines and the first seven interface structure guidelines) should be used as the mandatory guidelines when designing for an aging population, including individuals aging with disabilities. The rest of UDMIG v.2.1 should be used as the recommended best practices.

Table 33 – UDMIG v.2.1

Design Elements Guidelines	Interface Structure Guidelines
Essential Guidelines	
1. Accuracy and precision	1. Same means of use
2. Informative feedback	2. Clear and understandable navigation structure
	3. Consistency with expectations
	4. Simple and natural use
	5. Dialogs that yield closure
	6. Maximized "legibility" of essential information
	7. Range of literacy and language skills
Advisory Guidelines	
3. Choice in methods of use	8. Internal locus of control
	9. Adaptation to users' pace
4. Minimization of hazards and unintended actions	10. Multiple and dynamic contexts
5. Different modes of use	11. Design appealing to all
	12. Right-, left- or no-handed use
6. Easy reversal of actions	13. Low physical effort
	14. Variations in hand and grip size
	15. Natural body position

3.2.1 Design Criteria for Mobile Apps

Based on the UDMIG v.2.1, the design criteria for a health and wellness self-monitoring mobile application for individuals aging with MS were developed. Each design guideline resulted in one or more corresponding design criteria, which were specified to be implemented in the app design.

UDMIG v.2.1 represent a set of performance guidelines. However, among the four founding design strategies, DfA is the only one that included prescriptive guidelines. Therefore, a number of design criteria are presented as prescriptive, and the majority as performance-based. Although the objective of both prescriptive and performance design criteria is to achieve usable design outcomes, they do so in very different ways. Prescriptive criteria focus on means and methods of achieving usability by dictating what must be done to achieve a usable outcome. This is largely achieved without specifying what the design of the outcome might look like. As a result, the more prescriptive design criteria are, the fewer design alternatives there are and therefore fewer ways to achieve a usable outcome. For example, DE guideline *Accuracy and Precision* provides a specific design criterion that the size of the buttons should be at least 16.5mm diagonally and 11.7mm square. In addition, it dictates the minimum contrast based on the WCAG 2.0 1.4.3 (WebAIM, 2016) level AA and level AAA. In contrast, performance design criteria focus on the product or results of the design process. Performance-based criteria suggest what the usable outcome should be without regard to how that outcome is achieved. As a result, performance design criteria provide greater flexibility in design outcomes by providing opportunities for designers to rely on their interpretation and creativity to achieve a usable outcome. For example, IC guideline *Dialogs that yield closure* provides a design criterion that the related information should be grouped, and the most frequent operations should be highest on the menu structure. The latter one focuses on the design outcome and leaves it up to the designer to determine what the related information is and how to group it, and what the most frequent operations within the design are.

3.2.1.1 Design Elements (DE) Guidelines and Criteria

3.2.1.1.1 Essential Guidelines

1. *Accuracy and precision*
    a. Size of the buttons is at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017);
    b. Minimum contrast: the visual presentation of text and images of a text should have a contrast ratio of at least 4.5:1 (Level AA), preferably 7:1 (Level AAA) except for the following:

i. Large Text: Large-scale text and images of large-scale text should have a contrast ratio of at least 3:1;

ii. Incidental: Text or images of text that are part of an inactive user interface component, that are pure decoration, that are not visible to anyone, or that are part of a picture that contains significant other visual content, have no contrast requirement;

iii. Logotypes: Text that is part of a logo or brand name has no minimum contrast requirement (WCAG 2.0 1.4.3) (WebAIM, 2016);

2. *Informative feedback*

   a. For every operator action, there is a system feedback, such as a beep when pressing a key or an error message for an invalid input value (Shneiderman & Plaisant, 2010);

   b. Provide an obvious feedback (visual, audio, and/or tactile) when a target is selected (Fisk et al., 2009);

   c. Offer a feedback about a confirmation of an activity and a current state (Fisk et al., 2009; Ljilja Ruzic & Sanford, 2017);

   d. For each icon provide a text description (Johnson & Finn, 2017);

3.2.1.1.2 Advisory Guidelines

3. *Choice in methods of use*

   a. Provide an option to select or deselect all user preferences such as voice input (e.g., Siri, voice control) in Settings, available as accessibility features in iOS (Gong & Tarasewich, 2004);

4. *Minimization of hazards and unintended actions*

   a. Provide text warnings as opposed to symbols and icons (Fisk et al., 2009);

   b. Avoid short-duration menu displays (Fisk et al., 2009);

c. Frequent and important actions should be visible and easily accessible (e.g., Next and Back buttons on the lower left and right side, Home page button on the upper left corner) (Fisk et al., 2009; Sanford, 2012);

d. Tap targets on touchscreens should be at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017);

e. Tap targets should be in colors that stand out, and arranged in linear order (L. R. Kascak, Liu, & Sanford, 2015; S. T. Lee, Liu, Ruzic, & Sanford, 2016);

f. Avoid use of attention-catching techniques, such as flashing and scrolling text and images in the periphery (Fisk et al., 2009);

5. *Different modes of use*

a. Use alternative interaction modes such as sound, vibration, and light (Sanford, 2012);

b. Provide both tactile/haptic and auditory feedback with keypads (Fisk et al., 2009);

c. Provide several alternative voices (Gong & Tarasewich, 2004);

d. Provide redundant visual presentation of essential information (e.g., color, icons, and text) (Sanford, 2012);

6. *Easy reversal of actions*

a. Provide “Are you sure?” prompts for important actions that can be disabled in Settings (Fisk et al., 2009; L. R. Kascak et al., 2015);

b. If an error is made, the system should be able to detect the error and offer a prompt message for handling the error (e.g., if an entry for weight is skipped, provide a text message “Please enter a target weight”) (Shneiderman & Plaisant, 2010).

3.2.1.2 Interface Structure (IS) Guidelines and Criteria

3.2.1.2.1 Essential Guidelines

1. *Same means of use*
   a. Eliminate specialized design and language (Sanford, 2012);
   b. Provide one hardware and software application that allows individualized preferences (Ljilja Ruzic & Sanford, 2018);
2. *Clear and understandable navigation structure*
   a. Use the same design elements for the navigation from page to page, such as next and back buttons or similar (L. R. Kascak et al., 2015; S. T. Lee et al., 2016; Ljilja Ruzic & Sanford, 2017);
   b. Have navigation assistance (e.g., menu, instructions) for how to navigate to specific points in the system, which includes navigation to not only the home page, but also any relevant page (Fisk et al., 2009);
   c. Provide specific, clear, and evident instructions for every step of the actions, and allow users to disable these instructions in Settings and on the instructions page (Ljilja Ruzic & Sanford, 2017);
   d. Provide more than one way to go to different pages while keeping the consistency (Ljilja Ruzic & Sanford, 2017);
3. *Consistency with expectations*
   a. Identical terminology is used in prompts, menus, and help screens (Fisk et al., 2009);
   b. Consistent commands are employed throughout (e.g., Next, Back) (Fisk et al., 2009);
   c. Ensure standardized format and keep consistent location of target items within (e.g., navigation buttons, Settings button, and error messages should always appear at the same location) (Fisk et al., 2009);

4. *Simple and natural use*
    a. Avoid use of the picker (Ljilja Ruzic & Sanford, 2017);
    b. Avoid scrolling text because it is difficult to process, especially horizontal formats; use a slow scrolling rate if it cannot be avoided (Fisk et al., 2009; Ljilja Ruzic & Sanford, 2017);
5. *Dialogs that yield closure*
    a. Group related information and have most frequent operations highest on the menu structure (Fisk et al., 2009);
    b. Indicate clearly on the middle of the top navigation bar where the user currently is at any point of time (e.g., diary, reports, games, symptoms) (Fisk et al., 2009);
    c. After users save any data, provide the information that their records have been saved and secured (Ljilja Ruzic & Sanford, 2017; Shneiderman & Plaisant, 2010);
    d. Make it clear how to navigate to all main points of the interface from the homepage (i.e., main functional features on the home page), and how to go back to homepage from any other page (i.e., home page button on every page) (Ljilja Ruzic & Sanford, 2017);
    e. Make it clear which option is active (i.e., selected state) and what the consequences of an action are (i.e., by pressing the selected button and Next button the selected feature page will open) (Fisk et al., 2009; Ljilja Ruzic & Sanford, 2017);
6. *Maximized "legibility" of essential information*
    a. Size of the buttons is at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017);

b. Whenever possible use 14-point and bigger serif or sans serif fonts (i.e., use Helvetica primarily, and use Arial and Times Roman as secondary options), and use at least 12-point when not (L. Kascak, Rebola, et al., 2013b);
c. Avoid cursive and decorative fonts and use of all uppercase letters (Fisk et al., 2009);
d. Provide good structure (e.g., grammar) in spoken and written text (Fisk et al., 2009);
e. Provide video conferencing in addition to talking on a phone (Fisk et al., 2009);

7. *Range of literacy and language skills*
    a. Avoid use of technical language (Fisk et al., 2009);
    b. Keep reading level of text material at grade 10 or below (Fisk et al., 2009);

3.2.1.2.2 Advisory Guidelines

8. *Internal locus of control*
    a. Provide a choice of linear vs. random access (L. R. Kascak et al., 2015; S. T. Lee et al., 2016);
9. *Adaptation to users' pace*
    a. Profile provides personalization option for users' skill levels: novice to expert users (Gong & Tarasewich, 2004; Shneiderman & Plaisant, 2010);
10. *Multiple and dynamic contexts*
    a. Users can configure input and output to their needs and desires (e.g., text size, brightness) in Settings (Gong & Tarasewich, 2004);
    b. Allow for a configuration of the context, such as environmental conditions (e.g., brightness, noise levels, weather), and presence of strangers and locations that restrict use of some app features (e.g., speech input and output in libraries) (Gong & Tarasewich, 2004);

11. Design appealing to all

a. Provide color palette that can be used by colorblind users;

12. Right-, left- or no-handed use

a. Place main navigation buttons of equal importance accessible for both right- and left-handed users (e.g., Next and Back buttons at the lower left- and right-hand side) (S. T. Lee et al., 2016);

b. Provide speech input to allow for no-handed use (Gong & Tarasewich, 2004);

13. Low physical effort

a. Avoid double-clicking and use single tap instead (Fisk et al., 2009);

b. Minimize steps (i.e., basic tasks) when possible (Fisk et al., 2009);

14. Variations in hand and grip size

a. If the targets are large enough (at least 16.5mm diagonally and 11.7mm square), a spacing between them can be zero (Fisk et al., 2009; Johnson & Finn, 2017);

b. If targets are small, make spacing between them visible (e.g., 3mm) (Fisk et al., 2009; Johnson & Finn, 2017);

c. If possible, place tap targets near the center or the bottom of the screen (Johnson & Finn, 2017);

15. Natural body position

a. Place main navigation buttons of equal importance at the bottom of the screen (e.g., Next and Back buttons at the lower left- and right-hand side) (S. T. Lee et al., 2016).

3.2.2 Discussion

I refined the UDMIG v.2.1 to ensure usability of future mobile applications by older adults, including individuals aging with disabilities. A universal design approach was used to accommodate all users to the greatest extent possible. Based on each UDMIG v.2.1 guideline, corresponding design criteria were created to guide the design of MS Assistant.

3.3 Summary

Two formative studies (i.e., needs assessment study and usability of current MS-specific apps) discovered a need for an evidence-based mHealth app, which would address the health and wellness self-management needs in people aging with MS and provide a usable interface for an aging population, including those aging with disabilities. The two studies resulted in two sets of design and usability recommendations for the mobile interfaces to better assist individuals aging with disabilities and improve their QOL. The studies identified the functional and design features in MS-specific apps that meet the needs of people aging with MS. In addition, this research stressed the importance of having a comprehensive self-management mHealth app with simplified interface design. Moreover, it described refined UDMIG that include people aging with disabilities and listed the design criteria to guide the design of MS Assistant.

CHAPTER 4. DESIGN AND TESTING OF THE MHEALTH APPLICATION TO VALIDATE THE UDMIG V.2.1

The purpose of this chapter is to address specific aim 4 and to answer research questions 4 and 5. Research Question 4: *What is the effectiveness of the design features in MS Assistant designed based on the UDMIG, in meeting the usability needs of individuals aging with MS?* To answer Research Question 4, two iterative evaluations of the mHealth app were conducted to test the effectiveness of the design features with the purpose to validate the UDMIG. These studies reported that the UDMIG applied to the design of MS Assistant meet the usability requirements of individuals aging with MS. Research Question 5: *What is the effectiveness of the functional features in MS Assistant in meeting the health and wellness needs of people aging with MS?* To answer Research Question 5, the utility evaluation of MS Assistant with the end-user population was conducted, which confirmed that the mobile app and its functional features meet their health and wellness self-management needs. Moreover, I designed and developed the self-management mHealth application, MS Assistant, to validate the UDMIG.

4.1 Design of MS Assistant

Two formative studies described in the previous chapter presented a need for an evidence-based mHealth app, which would address the health and wellness s elf-management needs in people aging with MS and provide usable interface for all users, to the greatest extent possible. These studies resulted in a number of recommendations for the mobile interfaces to better assist individuals aging with disabilities and improve their QOL. More specifically, this research stressed the importance of having a comprehensive self-management mHealth app with simplified interface design. In addition, MS Assistant was designed based on prioritized UDMIG v.2.1, both mandatory and advisory guidelines.

I designed MS Assistant as a holistic app, which provides the functions identified in the needs assessment study (i.e., health and wellness self-management through diary, MS news and resources, social support, games and VR, keeping and communicating health and wellness data, telehealth) via personalized app with reminder systems and alarms. The app provides goal setting and emergency contacts as additional functions. Moreover, it communicates with the healthcare providers, caregivers, and family members by sending immediate messages in a case of an emergency. Moreover, I designed the interface of MS Assistant based on all the UDMIG design criteria to provide universal usability and simple and clear interactions and navigation.

4.1.1 Functions

MS Assistant was designed to provide eight functions, to allow for personalization, and to assist with medication adherence and other daily tasks with alert/reminder systems. Six out of these eight functions were selected based on the findings of a previous qualitative study (Ljilja Ruzic & Sanford, 2018), which was conducted to identify the specific needs for self-management of health and wellness among people with MS and to recognize the opportunities to meet those needs through mobile apps. A number of preferred functions were identified and grouped into eight categories (i.e., daily self-reporting of health and wellness, keeping and communicating health and wellness records, education, social support, alert and reminder systems, virtual reality games, telehealth, personalization). I added goals and emergency contacts as additional important functions. Setting specific difficult goals tasks leads to a behavior change and higher performance compared with a lack of or vague goals (Strecher et al., 1995). Therefore, goal setting may help individuals with MS manage their condition in a better way. Emergency contacts provide a fast access to placing a call to healthcare providers, caregivers, and family members.

The eight functions include diary, reports, MS friends, games, education, goals, vitals, and emergency.

Diary provides a comprehensive tool for understanding the condition on a daily basis and over time, and how best to manage it through everyday self-management tasks, such as mood, symptoms, energy level, activity, sleep length and quality, and diet.

Reports allows users to compile their health management data into useful reports that can be shared electronically with healthcare providers and caregivers.

MS Friends is a social support feature that connects users with other people with MS to share their experiences and everyday challenges.

Games features VR games that would enable users to perform real-world activities that they might find challenging. In addition, this feature has cognitive and classic games that help people with MS with cognitive functioning, and physical games, which help them with the balance.

Education provides the latest news and research about MS as well as health and wellness tips.

Goals enables users to set up their personal health and wellness goals to keep them motivated and inspired.

Vitals offers remote health and wellness monitoring through the Bluetooth connected devices, such as blood pressure monitoring devices, weight scales, sleep and activity trackers (e.g., Fitbit), and similar.

Emergency lets users place calls directly to their healthcare providers, caregivers, and 911.

4.1.2 Information Architecture

Information architecture was explored through the ideation sketches first. Navigation, layout, and interaction design were investigated to understand the possible app designs and create three different wireframes of MS Assistant (Figure 7).

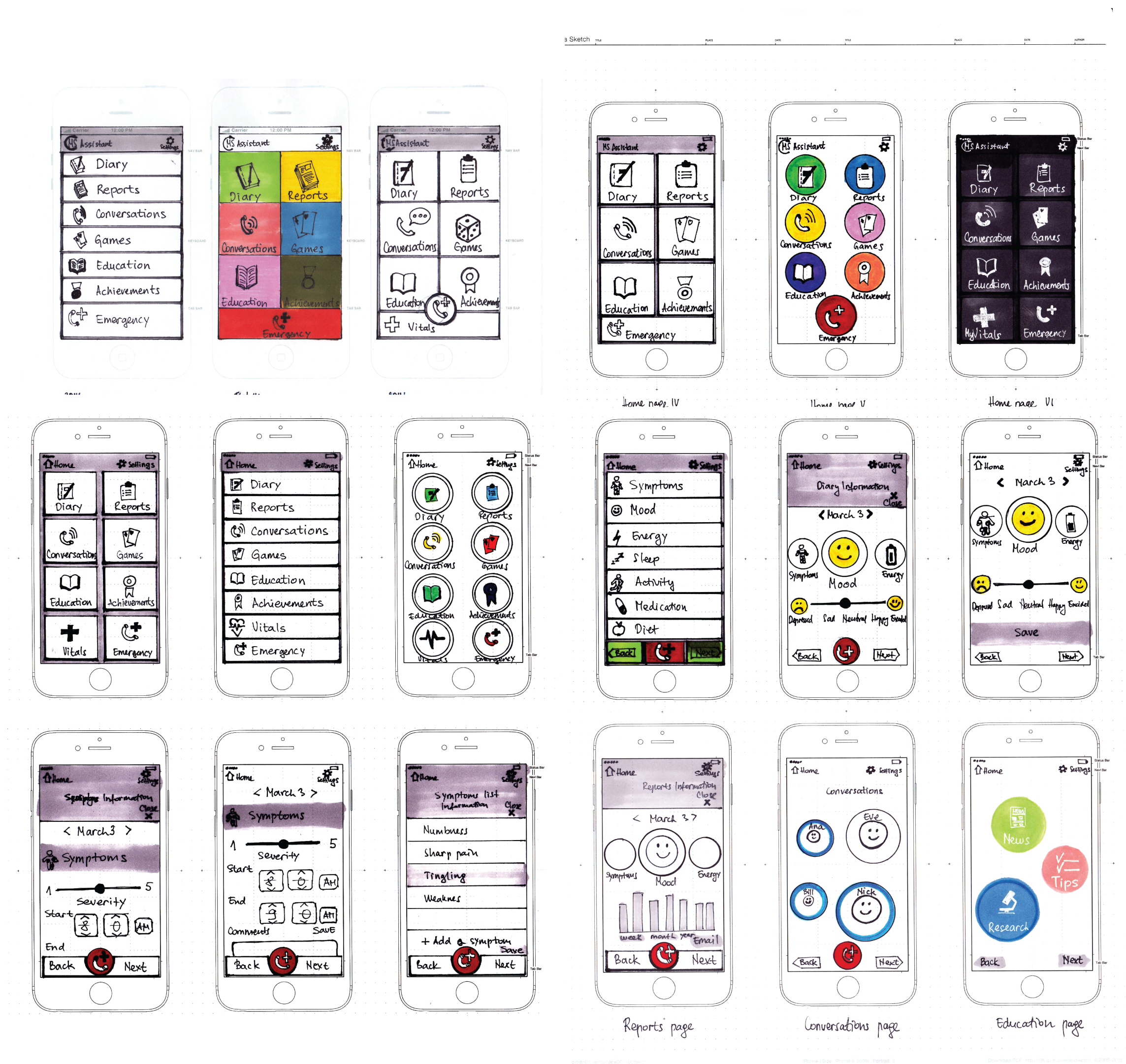


Figure 7 – Ideation sketches exploring the information architecture

4.1.2.1 Three Versions of the Wireframes

Using Balsamiq Mockups as a fast prototyping software, three versions of the app wireframes were designed. All three versions complied with the design criteria based on UDMIG v.2.1. However, the comparison of the compliance was performed to choose the final version of the app.

Version 1 had both linear and random-access interface (Figure 8). Linear navigation allowed users to go through the pages by tapping on the selection and then on the Next or Back buttons. They can navigate through the whole interface in a linear fashion by using the Next and Back buttons on every page. In addition, when the user taps on any button, the button changes to the selected colored background and white text that visually emphasizes the selection. After a selection is made, the Next button takes users to the following page of the interface. To change the selection, a user can tap on the button again to deselect it.

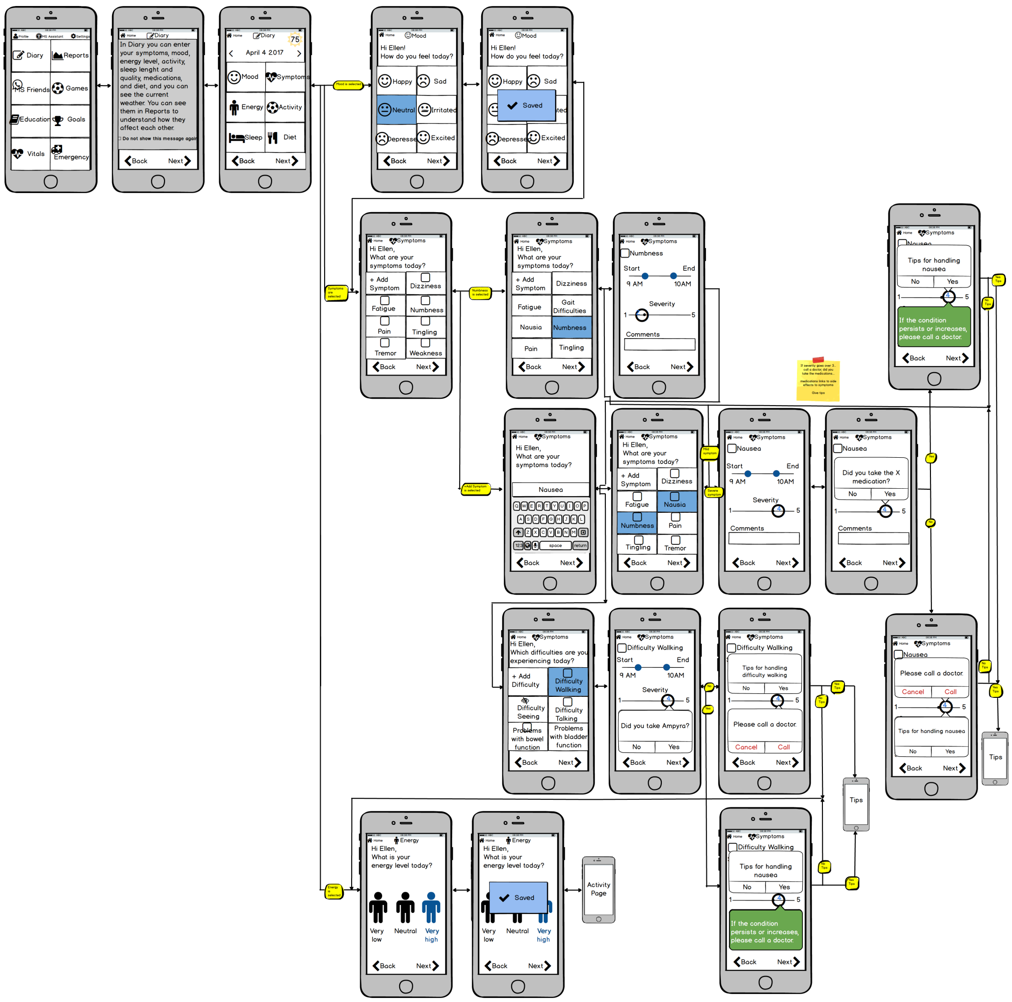


Figure 8 – Version 1

Version 2 provided random access through the main buttons on the Home page and the drop-down menu on each page (Figure 9). In addition, the linear interaction was provided with Save and Next buttons on every page. Save button provided the confirmation of activity and confidence in successful task completion.

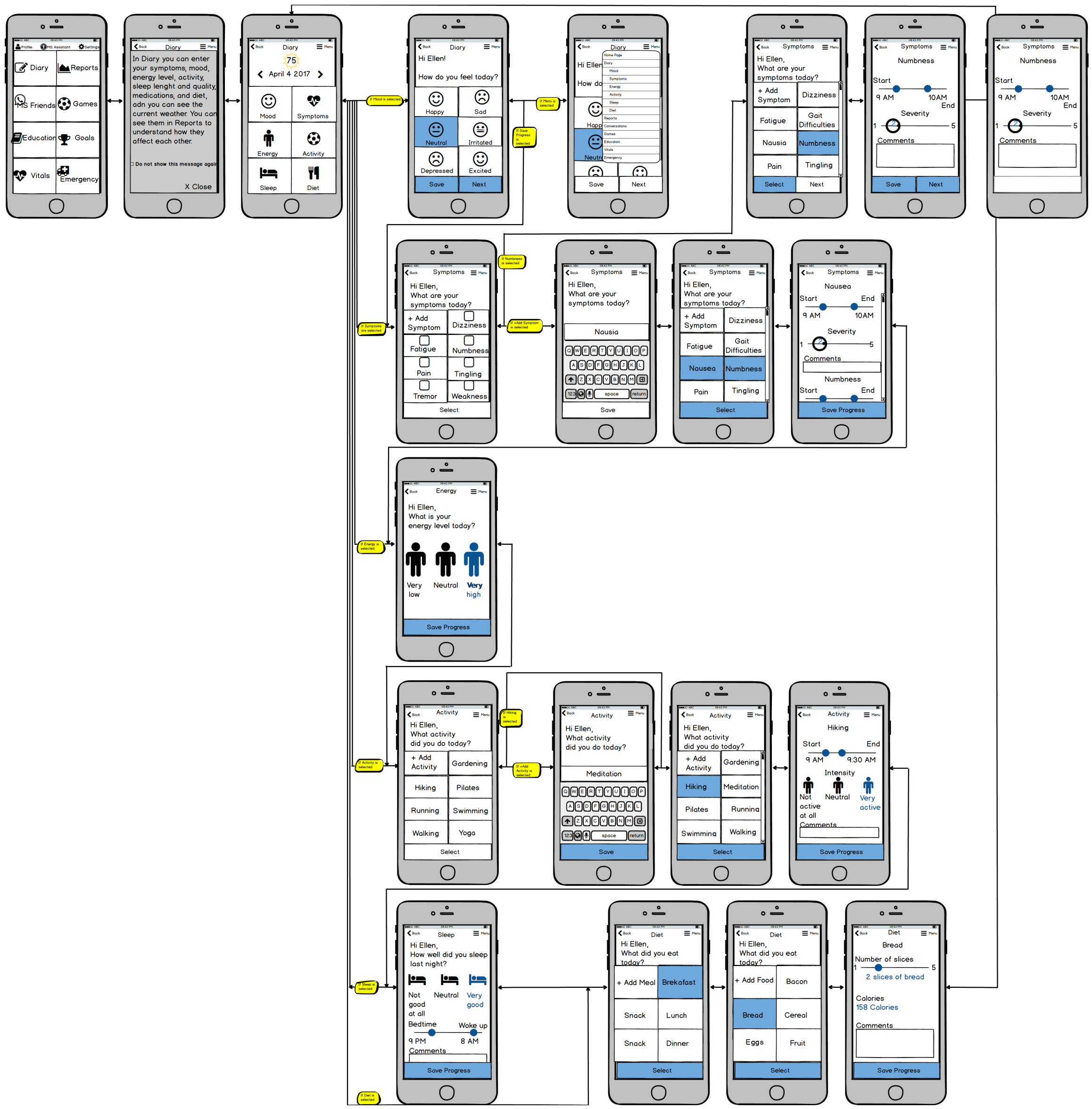


Figure 9 – Version 2

Version 3 of MS Assistant provided linear navigation with Save and Next buttons (Figure 10). In this version, the random access was provided through the large slider with all the buttons on it. Current and selected buttons on the slider were enlarged to provide visual and motor affordances. In addition, a drop-down menu was provided as well to offer more choices in navigation.

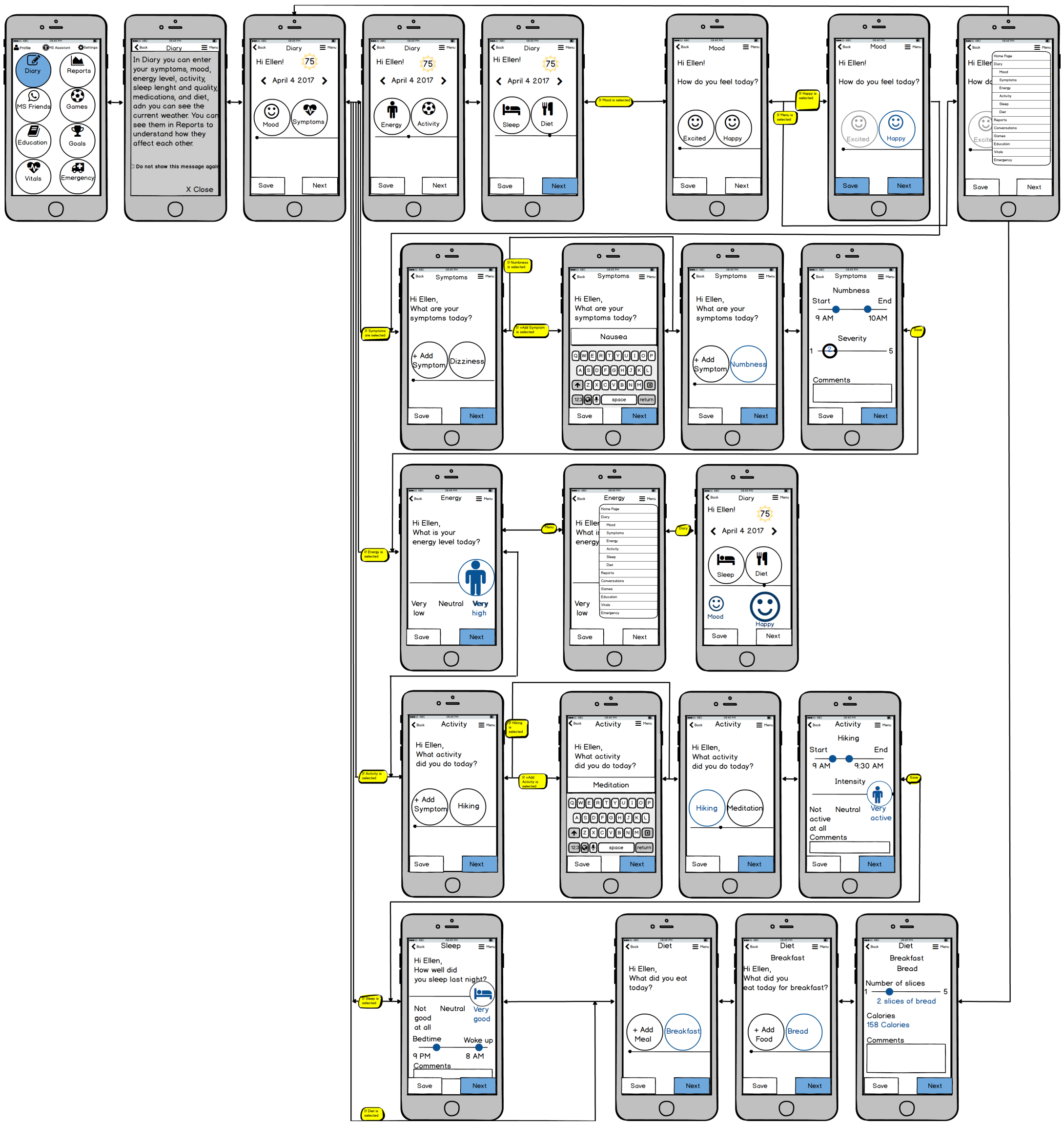


Figure 10 – Version 3

4.1.2.2 Choice of the Final Version of the mHealth Application Based on the Compliance with the Design Criteria

The comparison of the compliance of three versions of the app was performed to choose the final version. For example, Interface Context design guideline number 13. Low physical effort has design criteria to minimize steps (i.e., basic tasks, such as pressing a key). To avoid vertical scrolling for the all three versions of the app, a design decision was made to add new pages in a case of multiple selections and a larger number of the buttons.

Finally, after weighing design criteria against the three versions of the app, I chose Version 1 as the final one.

4.1.3 Structure

MS Assistant provides two types of navigation: linear and random access. Linear interaction allows users to go through the pages by making or skipping a selection and pressing the Next button. Users can go through the whole interface in a linear fashion by using the Next and Back buttons on every page, which provides consistency and simplicity. After a selection is made, the Next button takes users to the following page of the interface. When the user taps on any button, the button changes to the selected colored background and white text that visually emphasizes the selection (Figure 11). To change the selection, a user can tap the button again to deselect it. To navigate through the pages, the user can tap on the Next and Back buttons located at the bottom corners of the screen (Figure 11). For example, after tapping on the Diary button users are taken to the first Diary page where they can select the Mood. The selected state of the Mood button confirms the selection, and Next button takes users to the Symptoms page. Users are through all the Diary pages by tapping the Next buttons. After making the final selection on the Diet pages, users are taken to the Home Page. In addition, for the expert users and ones who prefer a direct selection, all of the functional features are accessible from the Home page.

Moreover, every page has the Home and Back buttons to allow an easy random access. Back button takes users to the main Diary page and directly make selections.

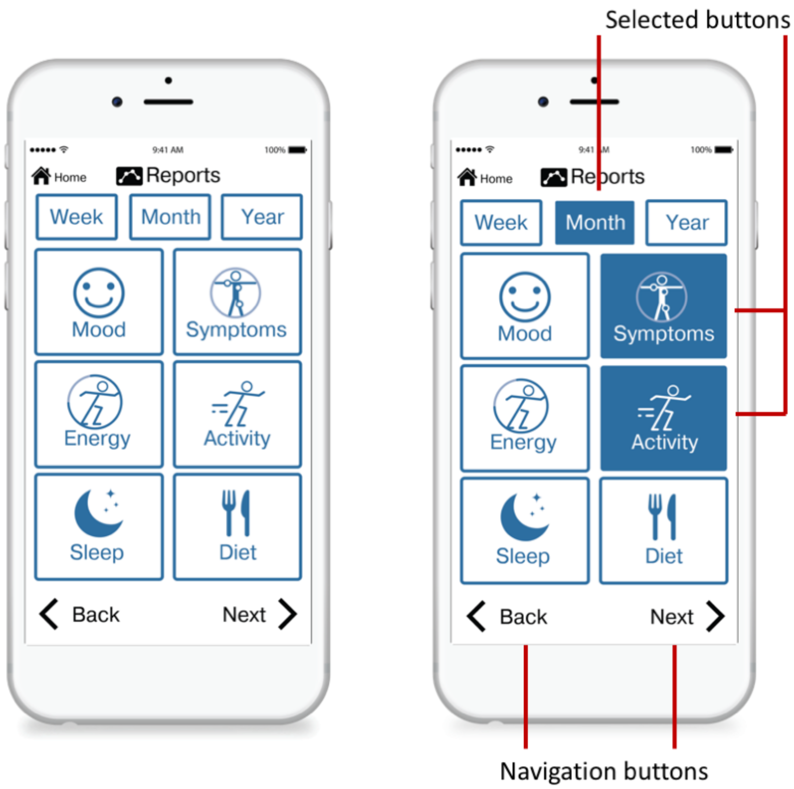


Figure 11 – Linear interaction, Reports pages

Random access allows for skipping the options and for a faster pace of the navigation through the direct selection (Figure 12).

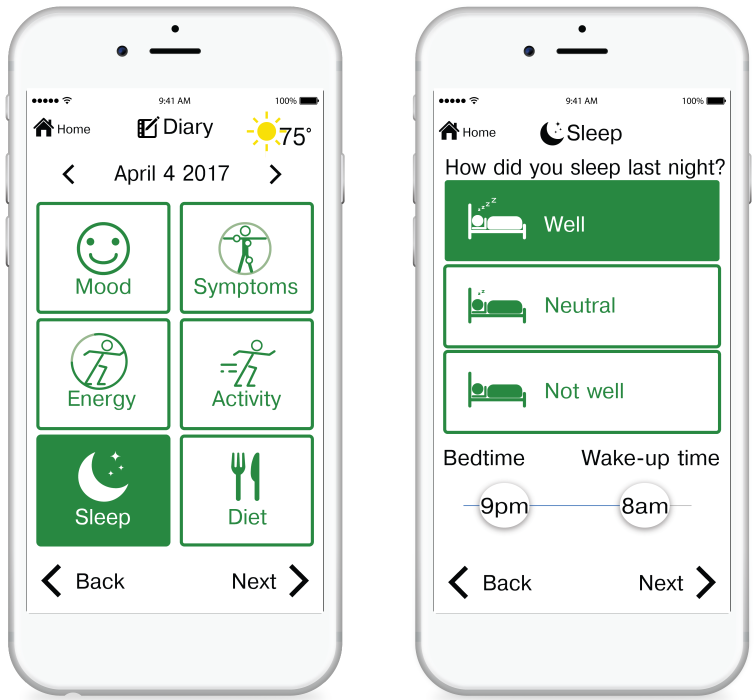


Figure 12 – Random access, Diary pages

4.1.4 Design Decisions

Design decisions for MS Assistant were based on all the UDMIG v.2.1 and corresponding design criteria.

4.1.4.1 <u>Design Elements (DE) Guidelines</u>

4.1.4.1.1 Essential Guidelines

1. Accuracy and precision

To facilitate the accuracy and precision required to accommodate different abilities, preferences, situations, contexts of use, ages, novice and expert users, and enhance users' experience, provided screen characters and targets are designed to be conspicuous and accessible (e.g., font size is at least 12-point and preferably 14-point size (Finlayson, 2002), the button size is at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017)). In addition, every function is presented by its color of the touch buttons on the Home Page and throughout the app (Figure 13a). The color scheme for Home Page buttons (i.e., functional features) is chosen to pass the assessment against the WCAG 2.0 1.4.3 (WebAIM, 2016) color contrast success criteria. Contrast is maximized by using black on white text.

2. Informative feedback

When the user taps on any button to make a selection, there is an audio feedback and the button changes to the selected state button with a colored background and white text and icon that visually emphasize the selection. A vibratory feedback was not possible to implement on iPhone 6, which is a major drawback of this model. However, it is highly recommended, and it is possible to implement it on iPhone 6s and iPhone 7 devices. An error message shows up on the screen after the user creates an invalid input value. After users finish all the tasks in the last section of Diary, which is Diet, they are taken to the Home page by tapping Next button.

4.1.4.1.2 Advisory Guidelines

3. Choice in methods of use

Different inputs and choices of input to accommodate variations in abilities, preferences, situations, and contexts of use are available in Settings as Input and Touch selections. For example, speech input through Siri and voice control is available for users.

4. Minimization of hazards and unintended actions

Text warnings, as opposed to symbols and icons, are provided in the form of prompts that can be disabled in Settings. Frequent and important actions are visible and easily accessible by placing Home button on the navigation top bar and Next and Back buttons on the bottom of the screen on every page (Figure 13b). Short-duration menu displays are eliminated because of the slower processing speed of an aging population. Instead, after the user taps on any button, the button changes to the selected state that lasts until the user taps on Next button or they decide to deselect it. Home page buttons are designed in colors that stand out (Figure 13a).

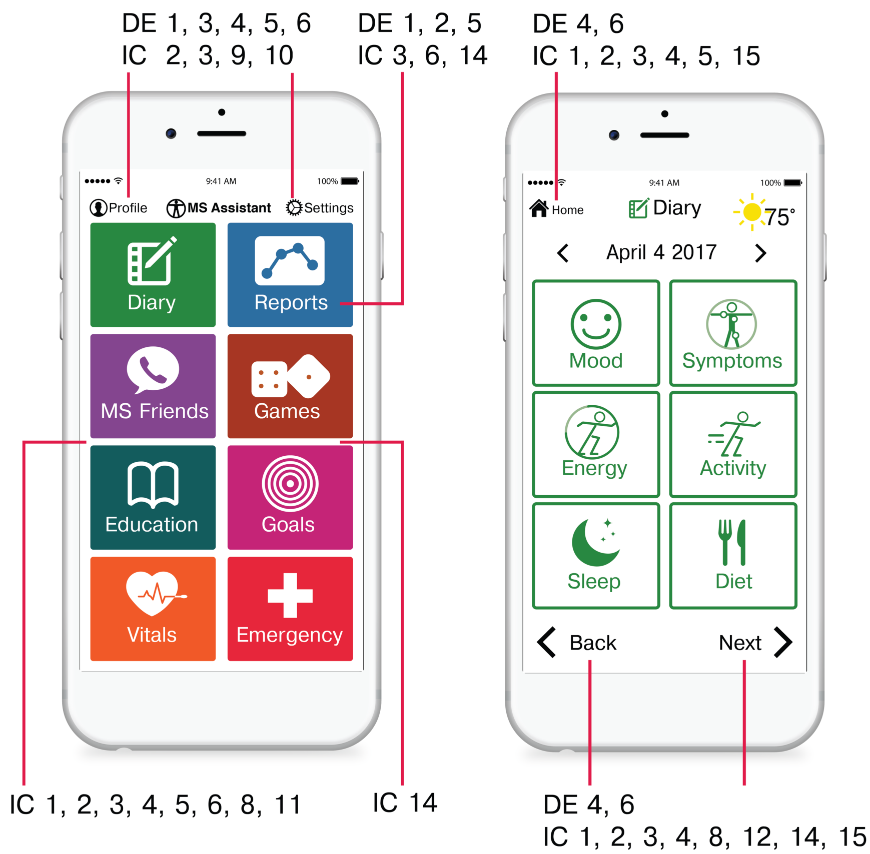


Figure 13 – Homepage (13a) and Diary page (13b)

5. Different modes of use

Different modes (pictorial, verbal, tactile) for redundant presentation of essential information to accommodate different abilities, preferences, and contexts of use are available and can be selected and deselected in Settings as Output and Touch accommodations. For example, alternative interaction modes such as sound, vibration, and light, haptic and auditory feedback with keypads, and several alternative voices can be selected. In addition, all touchscreen buttons provide redundant visual cues through color, icons, and text. Because of the limitations of iPhone 6, vibration (haptic) feedback is not available for this version and can be used on the iPhone 7 version and above.

6. Easy reversal of actions

Fail-safe features are provided to minimize hazards and errors. The units of reversibility are a single action, a data entry, or a complete group of actions. For example, “Are you sure you want to send the reports to the selected contacts?” is a confirmation message after a user selects the reports and contacts, with reversion back to the contacts screen when users press “No” (Figure 14b). Easy reversal of an action is provided through the option to cancel unwanted task in this prompt message if the list of contacts is wrong. Similarly, if a target weight is skipped in the Goals, a text message “Please enter a target weight” shows up to remind the user to fill out the weight.

4.1.4.2 Interface Structure (IS) Guidelines

4.1.4.2.1 Essential Guidelines

1. Same means of use

The design goal is one mobile health and wellness app for all users, rather than accessible design for people with disabilities. As a universally designed system, the app design avoids segregating or stigmatizing users and provides participation by providing the same hardware and software application that allows individualized preferences.

2. Clear and understandable navigation structure

Users can choose to have linear navigation using the same type of linear navigation (e.g., Next and Back buttons) on every page or they can go back to Home page and use random access navigation to go directly to a function. Navigation assistance is provided with instructions for how to navigate to specific points in the system and Home page button on every page. Specifically, every functional feature has an Instruction page that explains the content and interactions. For those who no longer need instructions, they can be disabled on the Instruction page itself and in the Settings.

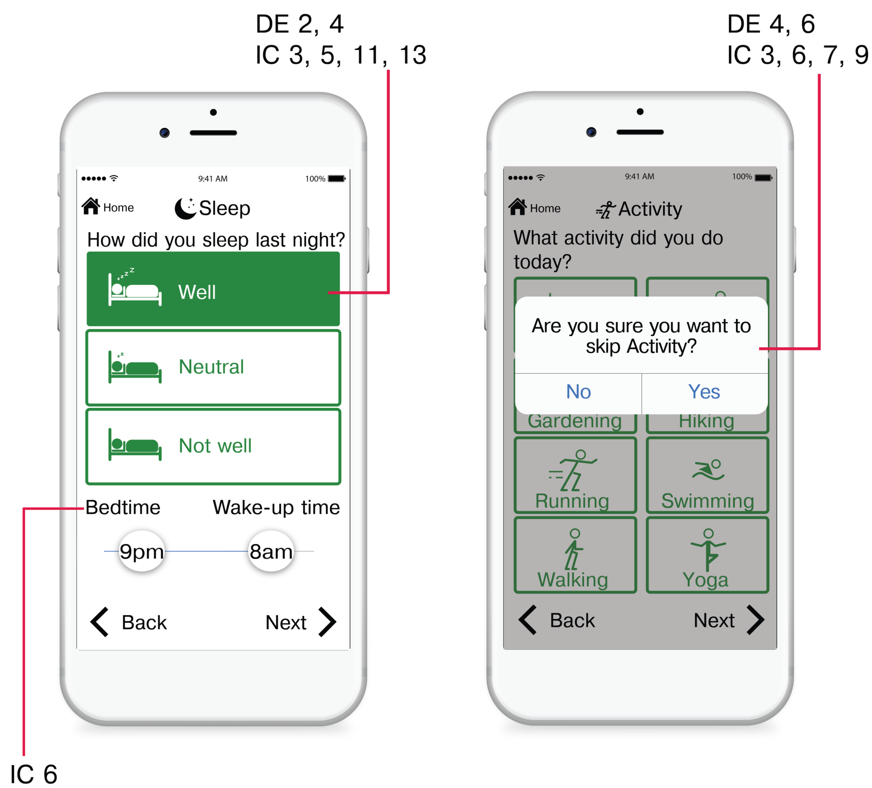


Figure 14 – Sleep page (14a) and Activity page with "Are you sure?" prompt message (14b)

3. Consistency with expectations

Consistent sequences of actions are required in similar situations. For example, users make a selection by tapping the button and the selected state of the button appears (Figure 14a). They navigate to the following page by tapping Next button on every page. Identical terminology is used in all screens, prompts, error messages, text messages, and information screens. Consistent commands are employed throughout the interface (e.g., Next and Back buttons, Home page button). Moreover, names, titles, color schemes, screen appearances, "look and feel," standard layouts, fonts, and font sizes are consistent throughout the app. In addition, consistency with pre-existing expectations is provided. For example, Next button is placed on the right-hand side, the Back button is located on the left-hand side, and selection is made by tapping a button.

4. Simple and natural use

Complexity is eliminated by having simple screen designs that require a small number of tasks per screen (Figure 15b). Next and Back buttons are placed on the bottom of the page to allow for the natural use and navigation. Use of the scrolling is eliminated by having the single task on one screen. In addition, use of the picker is eliminated, and a slider, keypad, and buttons are used throughout the interface. Moreover, navigation is simple for novice users, those with cognitive limitations, and older adults (i.e., linear navigation) as well as for expert/advanced users (i.e., random access). Use of all attention-catching techniques is avoided.

5. Dialogs that yield closure

Screens are designed in a way that the related information is grouped, and the most frequent operations are placed highest on the menu structure. For example, on the Activity page, its icon and the title are highest on the screen and placed on the top navigation bar, start and end time is at the top of the page after the name of an activity, followed by the distance. The comments section is at the bottom of the screen. Related information is grouped, in a way that every functional feature has its own pages and colors that increase the differentiation between the selections. Information is arranged consistent with its importance by having the icon and the title of the current functional feature at the top navigation bar (e.g., Diary with its icon, Mood with its icon, etc.) together with Home page button (Figure 15a). In addition, it is clear and simple to navigate to all main points of the interface from the Home page (e.g., Diary, Reports, MS Friends, Games, Education, Goals, Vitals, and Emergency), and to go back to Home page from any other page (e.g., Home page button, Next and Back buttons). It is clearly indicated which option is active by having the selected state of the tapped buttons, and what the consequences of an action are. For example, by tapping on the Next button after making a selection, the next page will open.

6. Maximized "legibility" of essential information

Screen characters and targets are designed to be conspicuous and accessible by designing the icons and buttons to be large enough to select easily. Helvetica 14-point font and bigger was the only font used.

7. Range of literacy and language skills

Research suggests that technical language might be difficult for older adults, as their educational attainment levels may be lower than that of younger adults (Connell et al., 1997). Therefore, simple conversational language is used for all text material, and reading level of text material is kept at grade 10 or below (Figure 15a).

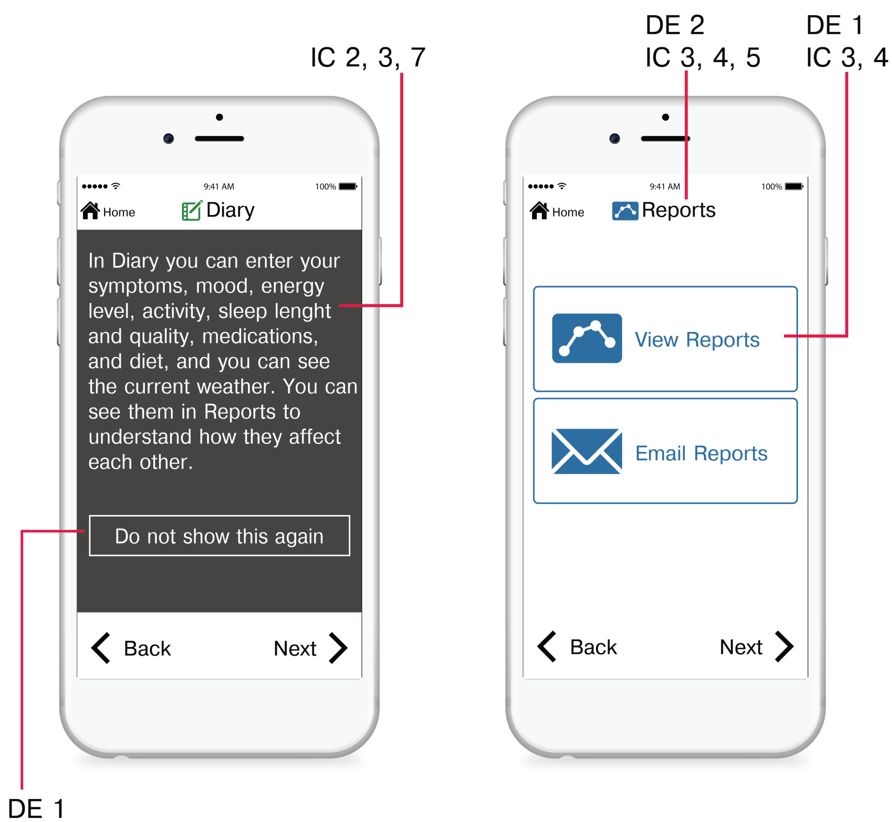


Figure 15 – Diary Instruction page (15a) and Reports page (15b)

4.1.4.2.2 Advisory Guidelines

8. Internal locus of control

The system should be designed such that users initiate actions rather than respond to them (Fisk et al., 2009). In addition, users can choose a navigation system and various preferences, such as linear vs. random access and novice vs. expert user navigation.

9. Adaptation to users' pace

The adaptable pace is provided in Settings and Profile to accommodate novice and expert users, different ages, abilities, preferences, situations, and contexts of use. Users can choose to navigate the app as novice or expert users, and they can personalize the app in the Settings. Pop-up menu durations are designed to be controlled by the user and require their confirmation (e.g., press "OK", "No", "Yes") to continue carrying out the commands.

10. Multiple and dynamic contexts

The Settings feature enables users to customize the input and output modalities to their needs and desires (e.g., text size, brightness) as well as the context, such as environmental conditions (e.g., brightness, noise levels, weather), presence of strangers and locations that restrict use of some app features (e.g., speech input and output in libraries) (S. T. Lee et al., 2016; Ljilja Ruzic & Sanford, 2018).

11. Design appealing to all

The app was designed to be appealing to all to enhance usability and marketability (Fisk et al., 2009; Zajicek, 2001). Color and its manipulation are important considerations for visual interfaces. MS Assistant has a color scheme that can be used by colorblind users.

12. Right-, left- or no-handed use

MS Assistant is designed to provide a right or left-handed access and use by having the main navigation buttons of equal importance at the lower left- and right-hand side (i.e., Next and Back buttons). Speech input is available for no-handed use.

13. Low physical effort

The app is designed to minimize repetitive actions and sustained physical effort to provide ease of use, efficiency, comfort, and minimize fatigue by using only single-tap (Connell et al., 1997) and by minimizing navigation steps.

14. Variations in hand and grip size

Large keys and appropriate inter-key spacing on a keypad are used to allow ease of use (Connell et al., 1997). For the small targets (less than 16.5mm diagonally and 11.7mm square), a spacing between them is designed to be visible (e.g., 3mm) (Finlayson, 2002). For the large targets, preferred is to provide the spacing between them although it can be zero. In addition, the tap targets are placed near the center or the bottom of the screen (Finlayson, 2002).

15. Natural body position

MS Assistant has the main navigation buttons at the bottom of the screen to provide comfort and minimize fatigue (Gulick, 1998).

4.1.5 App Prototype Development

MS Assistant was developed on iPhone 6 with Retina HD Display and 16:9 screen resolution of 750x1334 (326 ppi). Xcode 9.1 was used to develop the prototype.

Due of the limitations of the size of the top navigation bar, the design of the buttons on the Homepage was changed. For example, Profile and Settings buttons on the Homepage could not have the icons because the name of the app took space in between those two buttons.

Moreover, due to the limitations of iPhone 6 with the linear actuator instead of the Taptic Engine present in iPhone 7 and later versions, tactile feedback while touching the buttons specified by the design criteria could not have been implemented.

4.1.6 Discussion

The application of UDMIG v.2.1 to a mobile health and wellness app design was presented to illustrate and showcase the possible uses of the guidelines for a population of individuals aging with disabilities. mHealth mobile application for individuals aging with MS, MS Assistant was developed for this purpose based on the UDMIG v.2.1.

4.2 Effectiveness of the Design Features in MS Assistant

To answer Research Question 4, I conducted an expert review of MS Assistant to test the effectiveness of its design features with the purpose of validating the UDMIG v.2.1. Additionally, I present a refinement of MS Assistant based on the recommendations by the expert reviewers. Moreover, I conducted usability study with the end-user population to additionally test the effectiveness of the design features in mHealth app with the purpose of validating the UDMIG v.2.1.

4.2.1 Expert Review

For the purpose of evaluating the effectiveness of the design features as those were applied based on the UDMIG v.2.1 to the design of MS Assistant, I conducted an expert review in which expert evaluators rated the UDMIG-based design features that were implemented in MS Assistant, identified design elements that needed improvement, and recommended possible refinements. I collected user outcome measures, such as the ratings of the effectiveness of the application of the UDMIG design criteria to the app, and number and frequency of reported usability problems categorized based on their design features and characteristics. Additionally, I collected all verbally identified usability problems during the administration of the “talk aloud” protocol and categorized the data into the common themes to determine the main issues with the app.

4.2.1.1 Methods

4.2.1.1.1 Participants

Ten researchers and/or designers with experience in aging, accessibility, human-computer interaction, human factors, industrial design, universal design, and/or usability participated in the study. Inclusion criteria were that participants be of age 18 and older and that they have more than three years of experience in one or more of the areas of expertise in accessibility, usability, aging, human factors, universal design, human-computer interaction, and/or industrial design. Participants' expertise included accessibility (n=8), usability (n=8), aging (n=7), human factors (n=6), universal design (n=6), human-computer interaction (n=5), and industrial design (n=2) respectively. The mean number of years of their working experience was 13±8.82 years.

Experts rated their familiarity with the user interface design for people with MS, dexterity, cognitive, and visual limitations from being "not familiar" to "somewhat familiar" to "very familiar" (Table 34).

Table 34 – Ratings of familiarity with the user interface design for people with MS, dexterity, cognitive, and visual limitations

Familiarity with the user interface design for:	**Not familiar**	**Somewhat familiar**	**Very familiar**
People with MS	3	10	0
People with dexterity impairments	1	5	4
People with cognitive impairments	0	8	22
People with visual impairments	0	3	7

4.2.1.1.2 Testing Devices

MS Assistant app was tested on an iPhone 6 device. iPhone 6 has Retina HD display that is 4.7 inches in size with a 16:9 resolution of 1334x750 (326 ppi). Mr. Tappy ("Mr. Tappy," 2018), a kit for recording mobile devices from a user's point of view, was used to record the user interaction with the mHealth app. Camtasia ("Camtasia," 1995 - 2018), and

ScreenFlow ("ScreenFlow," 2018), screen recording software designs, were used to record the interaction of the participants with the app while using the app with Mr. Tappy.

4.2.1.1.3 Procedures

After signing the informed consent form approved by the Georgia Tech IRB, experts completed a demographic questionnaire about their areas of expertise and a number of years they have worked in the field. Experts rated their familiarity with user interface design for people with MS, dexterity, cognitive, and visual limitations on a scale from “not familiar” to “somewhat familiar” to “very familiar.” They then performed directed tasks using MS Assistant without any training or assistance. Experts received a simple script with ten tasks that included entering health and wellness data (i.e., mood, symptoms and related difficulties, energy level, daily activity, sleep length and quality, and diet), emailing the reports, calling MS friend, finding virtual reality games, reading the MS news, setting up the weight goal, inputting the blood pressure, calling the healthcare provider, entering the personal information, and increasing the text size (See Appendix E for the complete description of the ten tasks). Experts then used the UDMIG v.2.1 questionnaire to rate each guideline through its design characteristics, identified design elements needing improvement, and provided recommendations for their refinement.

4.2.1.1.3.1 UDMIG v.2.1 Design Criteria Questionnaire

Prescriptive design guidelines and standards are easy to interpret and to objectively assess. Assessment of performance guidelines is multidimensional since it incorporates both activity and participation (Sanford, 2012). All performance-based guidelines are subject to interpretation by experts as well as end-users to a certain extent, which makes objective measurement slightly difficult. UDMIG v.2.1 design criteria questionnaire rates agreement with achieving each of the design guidelines using the 5-point Likert scale where 1 = strongly disagree and 5 = strongly agree with each of the applicable design criteria. The versions of this questionnaire that correspond to the appropriate design criteria are intended to be used by end-users and to assist designers to think about the needs of the potential users who would interact with their mobile touchscreen applications.

The complete UDMIG v.2.1 design criteria questionnaire used for this expert review has 45 items (i.e., design criteria) (Appendix C). An example of the questionnaire based on some of the design criteria (e.g., one design criteria per guideline) used for the expert review is presented in Table 35.

Table 35 – UDMIG v.2.1 Design criteria questionnaire

Design Elements Guidelines	**Interface Structure Guidelines**
This application provides…	
1. Large enough button size (e.g., at least 16.5mm diagonally and 11.7mm square).	1. The same means of use for all users, by eliminating specialized design and signage.
2. Feedback about a confirmation of my activity and a current state.	2. The same design elements for the navigation from page to page (e.g., Next, Back Home page buttons).
3. Alternate methods of input and use, such as speech input.	3. Standardized format and keeps the consistent location of target items within (e.g., navigation buttons, and error messages).
4. Text warnings as opposed to symbols and icons.	4. Visible and easily accessible frequent and important actions (e.g., a location of Next, Back, Homepage button).
5. Different modes of feedback, such as sound, vibration, or light feedback.	5. Clear indication on the top of the page where the user currently is at any point in time (e.g., Diary, Reports, Games).
6. Easy reversal of my actions if I make a mistake, such as “Are you sure you want to send the reports to the selected contacts?”, with reversion back to the contacts screen when I press “No.”	6. The minimum contrast between the background colors against the images and text based on WCAG 2.0 1.4.3 Level AA, and preferably Level AAA.
	7. Reading level of text material at grade 10 or below.
	8. Choice of linear vs. random access.
	9. Personalization option to change my skill level from a “novice” to an “expert” user.
	10. Configuration of the output to my needs and preferences (e.g., text size, brightness).
	11. An aesthetically plausible color scheme that can be used by colorblind users.
	12. Main navigation buttons of equal importance accessible for both right- and left-handed users (e.g., Next and Back buttons at the lower left- and right-hand side).
	13. Use of a single tap throughout the app instead of double-clicking.
	14. The spacing between the small targets visible (e.g., 3mm).
	15. Main navigation buttons of equal importance at the bottom of the screen (i.e., Next and Back buttons).

4.2.1.1.4 Data Collection and Analysis

I calculated the mean and standard deviation of the rating for each guideline and the mean and standard deviation of ratings for each participant. Fourteen ratings for the participant number 8 were excluded because they skipped the page with ratings of the guidelines IC5c to IC13b.

Additionally, I analyzed the audio files during the participants' use of MS Assistant and administration of the talk aloud protocol to extract more usability problems they encountered during the interaction with the app. I used an inductive approach for data analysis.

As the primary researcher, I independently coded the transcripts and generated a preliminary set of codes. I coded for the themes (i.e., design features and related characteristics based on the identified problems) that participants reported in the UDMIG v.2.1 design criteria questionnaire. Another research team member then reviewed the sections of the transcript and associated codes. Next, we met to discuss the themes and refine the coding taxonomy. Labels (miscategorization), buttons (layout), keyboard (on-screen verification), too many clicks (physical effort), and lack of direction (navigation) were added themes. The coding had inter-rater reliability (i.e., Cohen's kappa) of 79.0%. The team met again to discuss, further refine, and expand some of the themes and related categories. Buttons and pages (navigation) and layout of the buttons themes were expanded, and feature request, page layout (lack of consistency), and lack of confirmation of an activity (navigation) emerged as themes. For example, buttons and pages (navigation) included a problem with Next and Back buttons, in addition to other navigation problems participants talked about (e.g., confusion with going to the other News pages and suggestion to use "Page 1 of 2"). Moreover, the layout of the buttons theme incorporated the layout of the View Reports and Email Reports buttons category from the questionnaire in addition to the problems with the other buttons. We developed a list of themes and each coder resampled additional 20% of the data. Inter-rater reliability (i.e., Cohen's kappa) of 81.0% was achieved between the two researchers.

4.2.1.2 Results

The results reporting the effectiveness of the design features in MS Assistant, and the effectiveness of the mHealth app are detailed in this section.

4.2.1.2.1 Effectiveness of the Design Features

Ratings of the design features as those were applied to the design of the mobile app following the UDMIG design criteria and *usability problems*, which were identified and reported by the expert users following each rating, are detailed in this section.

4.2.1.2.1.1 Ratings of the Design Features

Ten participants rated 45 items on the UDMIG design criteria questionnaire. The total number of responses was 436, with 14 missing responses that were not used in the analyses. The mean of all the ratings for design features was within a range of 3.90 – 4.89 (Table 36). Frequency of 4 and 5 ratings, which is a percentage of 4 and 5 ratings per design feature, was 60% - 100%. The design feature represented by DE6b (i.e., This app provides the system which can detect the error and offer a prompt message for handling it; if an entry for weight is skipped, provide a text message "Please enter a target weight") had the lowest mean of the ratings equal to 3.90 and the lowest frequency of 4 and 5 ratings, F=60%. This was the only mean value for design criteria that was lower than 4. Participants stated that the app provided a prompt message for handling an error. However, the prompt should "offer options to submit data without all responses submitted." Current prompts informed the users that they need to enter missing information and did not offer an option to skip certain fields. They made users fill out all the information on the page.

Out of a total of 436 ratings, 67% (n=292) of the design criteria was rated as 5. An additional 27% (n=118) were rated as 4. The lowest rating for any criterion was 2 (1.3%, n=6) and an additional 4.6% (n=20) were rated as 3.

Among the 10 participants, mean ratings ranged from 3.87 – 4.91. The participant with the lowest overall mean ratings (M = 3.87) did not give a rating higher than 4 to any individual criterion with 39 rated as 4 and 5 rated as 3, and 1 as 2.

Table 36 – Mean ratings (with standard deviations) of the design features by the expert users

Design Elements Guidelines	**Ratings, Mean, M**	**Ratings, Standard Deviation, SD**	**Frequency of 4 and 5 ratings, F (%)**
1.a. Large enough button size.	4.80	0.42	100%
1.b. Good contrast between the background colors against the images and text.	4.60	0.52	100%
2.a. Feedback about a confirmation of my activity and a current state.	4.00	0.94	80%
2.b. System feedback for my actions, such as a beep when pressing a key.	4.20	0.63	90%
2.c. Text description for each icon.	4.70	0.67	90%
2.d. Obvious feedback (visual, audio, and/or tactile) when a target is selected.	4.78	0.44	100%
3. Alternate methods of input and use, such as speech input (e.g., Siri, Voice Control).	4.60	0.70	90%
4.a. Visible and easily accessible frequent and important actions.	4.60	0.52	100%
4.b. Text warnings as opposed to symbols and icons.	4.60	0.52	100%
4.c. Buttons in colors that stand out, and arranged in linear order.	4.80	0.42	100%
5.a. Different modes of feedback, such as sound or vibration.	4.00	0.82	90%
5.b. Redundant visual presentation of essential information (e.g., color, icons, and text).	4.70	0.48	100%
6.a. Easy reversal of my actions if I make a mistake, such as "Are you sure you want to send the reports to the selected contacts?", with reversion back to the contacts screen when I press "No".	4.80	0.42	100%
6.b. The system which can detect the error and offer a prompt message for handling it.	3.90	1.10	60%
Interface Structure Guidelines			
1.a. The same means of use for all users, by eliminating specialized design and language.	4.40	0.70	90%
1.b. One hardware and software application for all users that allows individualized preferences.	4.70	0.48	100%
2.a. The same design elements for the navigation from page to page.	4.60	0.70	90%
2.b. Navigation assistance (e.g., menu, instructions) for how to navigate to specific points in the system, which includes navigation to the home page and to any relevant page.	4.60	0.52	100%
2.c. Specific, clear, and evident instructions, which can be disabled.	4.60	0.97	90%

Table 36 – Mean ratings (with standard deviations) of the design features by the expert users *(Continued)*

Interface Structure Guidelines	**Ratings, Mean, M**	**Ratings, Standard Deviation, SD**	**Frequency of 4 and 5 ratings, F (%)**
2.d. More than one way to go to different pages while keeping the consistency.	4.50	0.71	90%
3.a. Standardized format and consistent location of target items within.	4.60	0.52	100%
3.b. Identical terminology in prompts, menus, and help screens.	4.70	0.48	100%
4.a. The use of the picker is avoided.	4.80	0.42	100%
4.b. Scrolling text, especially horizontal formats, is avoided.	4.80	0.42	100%
5.a. Clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games).	4.80	0.42	100%
5.b. Related information in a group, and the most frequent operations highest on the page.	4.50	0.71	90%
5.c. Clear understanding of which button is selected and what are the consequences of my action.	4.67	0.50	100%
6.a. Large enough and legible fonts whenever possible.	4.78	0.44	100%
6.b. Good structure (e.g., grammar) in written text.	4.78	0.44	100%
6.c. Video conferencing in addition to talking on a phone.	4.67	0.71	89%
6.d. Cursive and decorative fonts and use of all uppercase letters are avoided.	4.89	0.33	100%
7.a. Understandable reading level of text material.	4.78	0.44	100%
7.b. The use of technical language is avoided.	4.33	1.12	78%
8. A choice of linear navigation vs. random access.	4.22	1.09	78%
9. Personalization to change my skill level from a "novice" to an "expert" user.	4.89	0.33	100%
10.a. Configuration of the display settings to my needs and preferences, such as text size, contrast.	4.89	0.33	100%
10.b. Configuration of the brightness, speech input and output, and similar in settings.	4.67	0.50	100%
11. Aesthetically plausible color scheme.	4.78	0.44	100%
12. Main navigation buttons of equal importance accessible for me.	4.78	0.44	100%
13.a. Use of a single tap throughout the app instead of double-clicking.	4.78	0.44	100%
13.b. Minimized steps (i.e., basic tasks) when possible.	4.22	0.83	78%
14.a. Visible spacing between the small buttons.	4.80	0.42	100%
14.b Zero or small spacing between the large buttons.	4.70	0.48	100%
14.c. The location of the buttons near the center or the bottom of the screen.	4.60	0.52	100%
15. Main navigation buttons of equal importance at the bottom of the screen.	4.80	0.42	100%

The mean values of the ratings were equal to 3.90 and above. Only one design feature had mean rating of 3.90 (DE6b), and all other features had mean ratings of 4 and above. Therefore, expert users rated all design features highly in MS Assistant.

Design feature represented by DE6b "the system which can detect the error and offer a prompt message for handling it" was rated the lowest because some participants thought that the prompt informed the users that they need to enter missing information and did not offer an option to skip certain fields (N=4) and rated it very low (rating=2, N=1; rating=3, N=3). The second lowest mean rating was given to two design features because of the lack of tactile feedback in an app due to the lack of the Taptic Engine in iPhone 6 model (M=4.00). Two participants rated DE2a "feedback about a confirmation of my activity and a current state" low (rating=2, N=1, rating=3, N=1), and only one participant rated the design feature characterized by DE5a (i.e., different modes of feedback, such as sound or vibration) lower than 4 (rating=2, N=1). The next lowest mean rating was equal to 4.20 and was given to DE2b "system feedback for my actions, such as a beep when pressing a key," due to the lack of the tactile feedback as well (rating=3, N=1). Two design features had mean rating of 4.22: IC8 "choice of linear navigation vs. random access" was rated by two participants lower (rating=2, N=1; ratings=3, N=1), and IC13b "minimized steps (i.e., basic tasks)" was rated low by two participants (rating=3, N=2). Design feature represented by IC7b (i.e., the use of technical language is avoided) had mean rating of 4.33 (rating=2, N=1; ratings=3, N=1). All other mean ratings of the design features were equal to 4.40 and above.

The highest mean rating (M=4.89) was given to three design features: IC6d "cursive and decorative fonts and use of all uppercase letters are avoided," IC9 "personalization to change my skill level from a "novice" to an "expert" user," and IC10a "configuration of the display settings to my needs and preferences." The second highest mean rating (M=4.80) was given to eight design features: DE1a 'large enough button size," DE4c "buttons in colors that stand out, and arranged in linear order," DE6a "easy reversal of my actions if I make a mistake," IC4a "the use of the picker is avoided," IC4b "scrolling text, especially horizontal formats, is avoided," IC5a "clear indication on the top of the page where the user currently is at any point of time," IC14a "visible spacing between the small buttons," and IC15 "main navigation buttons of equal importance at the bottom of the screen."

The difference between the lowest mean rating (M=3.90) for DE6b and the highest mean rating (M=4.89) for IC6d, IC9, and IC10a was statistically significant ($t(9)=2.951$, $p=.016$). The prompt needs to be redesigned to allow users a flexibility in navigation and an option to enter data they want, and not necessarily all data.

The second lowest mean rating (M=4.00) for two design features represented by DE2a and DE5a was significantly different than the highest mean rating (M=4.89) for IC6d ($t_1(9)=2.667$, $p_1=.026$; $t_2(9)=4.216$, $p_2=.002$, respectively), IC9 ($t_1(9)=2.667$, $p_1=.026$; $t_2(9)=4.216$, $p_2=.002$, respectively), and IC10a ($t_1(9)= 3.162$, $p_1=.012$; $t_2(9)= 4.216$, $p_2=.002$, respectively). Both design features that correspond to DE2a and DE5a were rated lower due to the lack of the tactile feedback. Participants would appreciate to have vibratory feedback implemented within an app, but they understood the limitations of iPhone 6 models and the lack of the Taptic Engine. The next lowest mean rating (M=4.20) for DE2b and the highest mean rating (M=4.89) for IC6d, IC9, and IC10a ($t(9)=2.981$, $p=.015$) were significantly different as well. This design feature was rated low due to the lack of the tactile feedback in iPhone 6 model as well.

The mean rating (M=4.22) that was given to two design features (IC8 and IC13b) and the highest mean rating (M=4.89) for IC6d ($t_1(9)=1.886$, $p_1=.092$; $t_2(9)=2.434$, $p_2=.038$, respectively), IC9 ($t_1(9)= 1.886$, $p_1=.092$; $t_2(9)=2.434$, $p_2=.038$, respectively), and IC10a ($t_1(9)=1.935$, $p_1=.085$; $t_2(9)=1.935$, $p_1=.085$, respectively) were significantly different only between IC13b (M=4.22) and the highest ones IC6d and IC9, respectively. There was no significant difference between IC7b (M=4.33) and the highest mean rating (M=4.89) for IC6d, IC9, and IC10a ($t(9)=1.733$, $p=.117$).

4.2.1.2.1.2 Usability Problems

After rating the design features, ten participants commented about the specific features and suggested possible design recommendations. I listed all identified usability problems with the app, grouped those issues into themes related to their design features and characteristics, and reported the number and frequency of participants reporting the problem (Table 37).

Table 37 – Design features and characteristics related to the identified usability problems

Themes	**Usability Problems**	**Design Feature and Related Characteristic**		**Ability Required to Perfom the Task**	**Number and Frequency of Participants, N, F (%)**
Navigation	Not clear whether required action was taken due to having to press Next after a single choice is made	Next and Back buttons, Navigation		Cognitive	N=7 F=70%
	Lack of understanding that there are two ways of navigation	Two ways of navigation, Navigation			N=2 F=20%
Labeling	Not clear labeling of buttons	Buttons, Labeling	Education		N=4 F=40%
			Emergency		N=2 F=20%
			Energized		N=1 F=10%
			Input, Output		N=2 F=22.22%
			Speech		N=1 F=10%
Design of UI elements	Profile and Settings buttons not prominent and visible	UI elements, Design	Profile and Settings	Visual	N=3 F=30%
	Header looks like a button		Header		N=3 F=30%
	Slider hard to use by the target population, the font and location of the numbers		Slider	Physical/ Visual	N=2 F=20%
Buttons	Lack of vibration	Buttons, Haptic feedback		Physical	N=3 F=30%
	Expected double-tap	Buttons, Single tap			N=1 F=11.11%
Keyboard	Lack of page scrolling with use of a keyboard	Keyboard, Page scrolling			N=2 F=20%
	Lack of spell check with use of a keyboard	Keyboard, spell check			N=1 F=10%
Page layout	Small spacing between the buttons	Button spacing, Layout		Visual	N=2 F=20%
	Layout, form, and location of View/Email Report buttons	View and Email Report buttons, Layout			N=1 F=10%
Contrast	Low contrast against the background (instruction page)	Background, Contrast			N=3 F=30%
Prompt	Lack of specificity and lack of flexibility (navigation)	Prompt, Content		Cognitive	N=2 F=20%
Font size	Small font size	Text, Font size		Visual	N=1 F=11.11%

Total of 3 participants (F=30%) reported low contrast on the instructions pages where white text on grey background and “Do not show this again” button in a selected state with green text on a grey background did not provide high enough contrast (Table 37).

1. Navigation: Seven participants reported problems with navigation due to having “to press on Next after a choice is made,” (P1) which “was not clear at first.” They either “expected to double click” (P6) or just click on the selection to open that particular page. Moreover, 2 participants reported that “Next” and “Back” buttons look like a part of the specialized use and design. However, all of them understood that Next and Back buttons are a typical of linear navigation, which is beneficial to an aging population that uses this app in a novice user mode only. Two participants were not sure whether there is more than one way to go to different pages (i.e., linear navigation using the Next and Back buttons and random-access).

2. Labeling: Labeling of buttons included a number of different usability problems and related suggestions. Four participants reported that “Education” should be renamed into “Digest,” “Resources,” or similar because “News” category did not belong in there. It was not clear that a healthcare provider would be listed under the functional feature named “Emergency” (N=2), but there was no agreement on the alternative location for it. P3 suggested that it should be moved under Reports as an additional sub-feature named Contacts. P1 stated they “didn’t want to click on it because I thought it would call 911,” but did not think any other location would be more suitable for it. Mood page had an “Energized” icon, which was confusing to 1 participant Diary had a category “Energy level.” They suggested that “Anxious and Excited are missing” (P3) and that “Energized could be elsewhere.” Another suggestion was to rename “Input” and “Output” categories of Settings into a non-technical language (N=2). 1 participant reported that “Speech” should be renamed into “Voice.”

3. Design of UI elements: Design of a number of user interface elements included 3 participants who reported that Profile and Settings did not look like buttons (P9) and that those should be redesigned to “stand out” (P6) and look more prominent (P6, P9). Design in Adobe Illustrator presented in this paper followed the guidelines strictly and made a distinction between the name of the app, MS Assistant, and Profile and Settings buttons on the first page. However, because of the limitations of iOS and the size of the top navigation bar, there was no space for the Profile and Settings icons because of the minimum font size dictated by the UDMIG v.2.1. Participants suggested that those two buttons should “look like buttons” (P9) with possibly adding a black border to them, relevant icons, or background color so that those look like the other buttons on the home page. In addition, 2 participants reported that top navigation bar icons that represent a title of the current page, including the weather icon, “look clickable” (P6). During the design phase, Adobe Illustrator prototypes made a clear distinction between the design of the home button and the title of the current page (e.g., Diary, Mood, Vitals, etc.). However, since the iOS limited the size of the top navigation bar and there was no compromise on the side of the font size, those two looked the same. P4 recommended that “header should look different than the home button.” Moreover, 2 participants commented that the design of the slider used on the symptoms, difficulties, and sleep pages probably needs a redesign because of the problems with motor control in individuals with MS, and their possible use of the stylus. 1 participant commented that the “numbers on the bottom should be on top of the slider” (P9).

4. Buttons: Three participants reported a lack of vibration while tapping the buttons even though they understood the limitations of iPhone 6 due to the lack of the Taptic Engine, which provides the vibration while tapping the buttons that was included in later iPhone versions. P6 “expected to double-click” (N=1). However, the single tap was implemented throughout the app due to the design criteria IC13a (i.e., Use a single tap throughout the app instead of double-clicking).

5. Keyboard: One participant reported that spell check should be provided with the use of a keyboard. Lack of page scrolling while using a keyboard was found problematic to 2 participants. Participants recommended to "add scrolling where additional input is needed." Scrolling was disabled throughout the interface because of the IC4c design criteria requirement.

6. Page layout: Total of three participants had problems with the page layout. For example, P5 reported that "View Reports" button should be placed above "Email Reports" button (N=1). Two participants reported that spacing between the top navigation bar and large buttons (e.g., Manual entry, Week, Month, Year buttons) should be increased.

7. Contrast: Two participants reported 3 times low contrast on the instructions pages during the use of the app.

8. Prompt: Two participants reported that "Sometimes (it is) not clear what info is missing but did get a general message about missing info" (P5) after getting the prompt message, and that the app should "offer options to submit data without all responses submitted" (P7).

9. Font size: One participant thought that the font size of the News articles was too small.

4.2.1.2.2 Effectiveness of the app

While using MS Assistant, participants verbally identified specific *usability problems*, and *positive aspects* of MS Assistant via "talk aloud" protocol administration and in some cases recommended possible design solutions. Audio transcripts were used to identify all *usability problems* with the app and *positive feedback*.

4.2.1.2.2.1 Usability Problems

I categorized all the issues with the app into the themes to identify usability problems, and I reported related design features and their characteristics (Table 38).

Table 38 – Usability problems (i.e., themes and problem explanations) with related design features and characteristics

Themes	Usability Problems	Design Feature and Related Characteristic		Ability Required to Perfom the Task	Number of Instances Problem was reported, n	Number of Participants, N
Navigation	Not clear whether required action was taken due to having to press Next after a single choice is made; Specialized use	Next and Back buttons, Navigation		Cognitive	12	N=7
Labeling	Not clear labeling of buttons	Buttons, Labeling	Education		7	N=7
			Emergency		7	N=7
			Energized		2	N=2
			Input, Output		9	N=7
			Speech		4	N=4
			News		1	N=1
			Diary		1	N=1
			Do not show this again		1	N=1
Design of UI elements	Profile and Settings buttons not prominent and visible;	UI elements, design (form and color)	Profile, Settings	Visual	5	N=5
	Header looks like a button;		Header		4	N=3
	Slider hard to use by the target population, the font and location of the numbers;		Slider	Physical/ Visual	7	N=5
	Not adequate icons;		Icons	Cognitive	5	N=3
	Lack of MS types options		MS type		1	N=1
Page layout	Layout, form, and location of the buttons (including View/Email Report buttons); Page layout; Missing information about the selection and navigation; not dynamic enough; smart app feature	Buttons, Page Layout			13	N=6
	Too small button spacing	Button spacing, Layout		Visual	4	N=4
Keyboard	Lack of page scrolling with use of a keyboard	Keyboard, Page scrolling		Physical	6	N=5
Prompt	Lack of flexibility (navigation)	Prompt, Content		Cognitive	4	N=3
Font size	Small font size	Text, font size		Visual	2	N=2
Contrast	Low contrast against the background	Background, Contrast			3	N=2
Single tap	Too many clicks required (physical effort)	Buttons, Single tap		Physical	1	N=1

Table 38 – Usability problems (i.e., themes and problem explanations) with related design features and characteristics *(Continued)*

Themes	**Usability Problems**	**Design Feature and Related Characteristic**	**Ability Required to Perfom the Task**	**Number of Instances Problem was reported, n**	**Number of Participants, N**
Feature request	Missing features	Feature, Feature request	Cognitive	11	N=6
Navigation	Lack of direction; Page design; Multiple selections	Buttons and pages, Navigation	Cognitive	12	N=6
Design	Wrong location and labeling of certain features	Labels, Miscategorization		10	N=5
Lack of consistency	Lack of consistency in page layout	Page layout, Lack of consistency		2	N=2
Keyboard	Lack of the on-screen verification with keyboard	Keyboard, On-screen verification		1	N=1
Lack of confirmation	Lack of confirmation that data was entered	Lack of confirmation of an activity, Navigation		1	N=1

1. Navigation: Seven participants reported 12 times problems with navigation due to having to press on Next after a single choice is made and the appearance of Next and Back buttons as specialized use.

2. Labeling: Labeling of a total of eight buttons was not clear to a number of participants. Seven participants reported 7 times that "News" category did not belong in "Education" and that it should be renamed. It was not clear to 2 participants that a healthcare provider would be listed under the "Emergency" (n=2), but they could not think of an alternative location for it. Two participants thought that an "Energized" icon on the Mood page was confusing because Diary had a category called "Energy level" (n=2). Their suggestion for a replacement was to name it "Excited." Seven participants stated 9 times that "Input" and "Output" categories in Settings sound as a technical language and that those would be confusing to a regular user. Four participants thought that "Speech" should be renamed into "Voice" (n=4). In addition to these relabeling suggestions reported with the UDMIG v.21. questionnaire, there were 3 more labels reported during the interaction with the app. One participant suggested once to rename "News" into "MS News," another proposed once to rename "Diary" into "Daily feelings" or "Daily something" (P6), and the third one recommended to rename "Do not show this again" button into "Hide" (P10).

3. Design of UI elements: Participants had problems with the design of 5 user interface elements, which is 2 more than reported in the questionnaire. Five of them stated that Profile and Settings did not look like buttons and suggested to redesigned them to look more prominent and like buttons by adding a black border around them, icons, and/or a background color (n=5). Three participants thought that the top navigation bar icons that have a function of a header look like buttons (n=4). Five participants commented 7 times that the design of the slider should be changed. P3 and P6 thought that an easier design element should be used instead because the individuals with MS would have problems using it due to their limitations with motor control and the use of the stylus. P9 thought that the numbers on the slider should be on top of it, and P10 suggested to change the font of the selected number compared to the range provided (i.e., 1 to 5). In addition to these design elements present in the results based on the questionnaire, 3 participants reported 5 times problems with the design of the icons. For example, Output icon in Settings looked like a sound (P5) and audio (P9), P9 suggested to replace Input icon with Speech icon and to change Speech icon itself, and P10 stated that Seeing icon in Difficulties looks happy and that it should be changed. Moreover, P9 commented once that the comment section for MS type was not visible and that it could be replaced with a drop-down menu offering the names and abbreviations of the four types of MS.

4. Page layout: The total number of 6 participants commented 13 times about the problems with the layout of the buttons, including View Reports and Email Reports buttons. Two participants reported that View Reports button should be above Email Reports button (n=2). In addition to the layout of the Email/View Reports buttons, there were 5 participants who reported 11 problems with the layout of other buttons. For example, P3 thought that Tips would be of great importance and interest to the target population, and that Tips should be placed first on the list, followed by News and Research. They and P7 suggested having the listing of all the headlines of the articles on the News page. Week, Month, and Year buttons on the Reports page were not clear at first to this participant, and P6 suggested to “maybe change the color of the (Week,) Month, Year buttons.” P4 suggested placing the “Read more” button on the News page on the bottom of the page. P10 said that the “names for the games are too long” and that I should “maybe change the layout to vertical buttons.” They thought that “overall, the design is nice, but I would make it more dynamic.” This participant did not understand the sequence on the 2 by 3 layout of the buttons on the Symptoms page. They thought that “if meditation (button) moves from the first place after a certain amount of (usage) time, would that be confusing?” in a case of a smart app. Reports pages should have “Page 1 of 2” on them. The small spacing between certain buttons (e.g., the Manual button in Vitals and Week, Month, Year buttons in Reports) and the top navigation bar was reported by 4 participants (n=4).

5. Keyboard: Five participants reported lack of page scrolling while using a keyboard 6 times.

6. Prompt: Three participants stated 4 times that when missing to fill out all the data on one page, the corresponding prompt makes them fill out all the information and lacks the flexibility to offer them the option to submit data without submitting all the responses. P10 suggested changing the text of the prompt to “Are you sure you want to skip X and Y?” The font size of the News articles was too small to 2 participants (n=2).

7. Other: Two participants thought that the font size of the News articles was too small. Two participants reported 3 times low contrast on the instructions pages during the use of the app. One participant thought that the drawback of using a single tap is that it requires too many steps. P10 complained that the app requires too many clicks and that they are “wondering how much effort I am saving” (n=1).

8. Additional usability problems: Additionally, there are 6 themes of problems identified during the interaction with the app, which were not reported on the questionnaire. Six participants requested 11 times that certain features could benefit the app. For example, P1 asked if there is any way to specify the body area in Difficulties. P3 suggested that in a case of two selections in Symptoms, after making the one selection the app takes you to that symptom's page, and then it takes you to the one-screen selection again to make the second one. They added that the weight goals should have displayed the user's current weight with the text "This is what your weight is right now." P5 requested a louder sound feedback with the use of the buttons, adding the MS experience within the Profile, adding the Resources to the list of News, Research, and Tips because "older adults don't know where to find resources," and adding the info box to the View Reports page that would say "Select one or more buttons and choose whether you want Reports." P6 suggested to have the option to check the email address of the person who would get the reports sent by the user, to "make it clear in the description of a friend who he/she is by listing the symptoms or something else" in MS Friends, and to clarify on the top of the Instruction page "what this page is" by possibly adding "Getting started". P7 thought that after the prompt about sharing the personal information, Profile page should have that information written again on the top of the page. P10 commented that in MS Friends "I would expect something about Mike to show up in a case of two people with the same name."

Five participants commented 10 times about the miscategorization of the certain labels. For example, P1 did not know where to enter data for numbness and where to find personal information. P6 thought that "Medications should be separate; not under Profile." P7 commented that it is "not intuitive" to look for "non-emergency contacts under Emergency; Emergency is 911", and that this "call should go under MS Friends." P9 "was not sure if Difficulty was on another page" and thought that Personal Information "would probably be in Diary." P10 added that "I would go to Diary for my Mood, symptoms. For energy level, because it is quantitative data, I would go to Reports." This participant stated that "I wouldn't link difficulty to symptoms." When looking for Reports, P10 said that "I could think also whether to go to MS Friends." P10 was not sure where to call a doctor, but after thinking about the available features, they thought that "Emergency and MS Friends makes sense."

Two participants reported lack of consistency in the page layout 2 times regarding the selections on two pages in the View Reports and Email Reports. P9 said that on-screen keyboard is problematic with verification because "I was looking for a back button. I don't see any indication that the focus is there (keyboard)."

Buttons and pages (navigation) theme was present 12 times in 6 participants. For example, P3 suggested that in a case of multiple selections, one at a time can be selected with a "loopback for more." P4 commented that it is "confusing to go from Symptoms to other screens if I want to skip something" and wondered if it is better "to go to the Home page from Symptoms or to go through all unwanted pages." They did not understand that Diary page offered random-access. The same participant complained that "when I went to Activity, Back (button) is taking me to the main (Diary) menu instead to Energy," which happened because the participant directly selected Activity from the Diary page. P5 thought that by tapping on the Next button on the News page, they were "going to the next page." This participant was not sure if they selected Mood "it would take me through everything," asked why Symptoms and Difficulties are not at the same level because these "are the same," and thought that "it should be clear there is no scrolling because of Back and Next buttons." P6 thought that I should "add another meal page after you go through one." P9 was confused that there is no "choice of eggs on the same page (with bread)," when both bread and eggs were selected. P10 commented when opened Diary Instructions page:

> *"I see a screen with a lot of text on it. When I first click on Diary, I would expect an input box. I see it's a prompt, but it doesn't look like a prompt."*

The same participants thought that the comment section on the Symptoms page was not clear:

> *"I wouldn't think to put that information in here. I would enter numbness related to arm in one log, and for legs in another. Not both in one."*

P10 also thought that "Email Reports would email reports by pressing (it)." The same participants reported lack of confirmation of activity after entering the data on the Symptoms page (n=1).

4.2.1.2.2.2 Positive Feedback

Participants had some positive feedback throughout their usage of the app. P3, P4, and P10 loved the icons, which made sense to them and looked "expressive." P3 liked the sound feedback with the slider and with a tap on the buttons. Settings had a "pretty good mix there." P4, P6, and P7 liked "the color scheme a lot" (P6). P4 liked the font size. P4 and P8 appreciated the ability to deselect information which would be shared by using the switches on the Personal Information page, and P5 liked that on the switches have green color when selected because "green means go, so I guess green means sharing," and that there was a confirmation message (i.e., prompt) "especially when I was sharing the information.". P4 commented that the "buttons are refreshingly large," how "it is nice that it (linear interface) is making me log in everything this way," and that the app was "nice and easy to use." Both P5 and P6 appreciated that the user could choose from many items and make multiple selections on View Reports and Email Reports pages. P6 and P10 liked the design of the Sleep page, and P10 commented:

> *"I like the Sleep screen. It saved me a click. Once I am done, the screen itself looks like a confirmation. This screen is more confirmative to me than a Symptoms screen."*

P10 thought that the Diet pages were designed in consistency with the linear interface and that "if I am eating two different things I would not expect that Next would take me to both selections (on one page). It is pretty linear, the app, so I wouldn't expect that." The same participants thought that "Energy screen is really good and clear," and that" the slide bar is really good because the slider is big." P10 added that:

> *"Back and Home (buttons) both take me to the Home page, which is good. Home is a reference point. I would press Home button to go to the Home page."*

P6 and P8 liked that there was a prompt before emailing the reports asking if the user wanted to email selected reports to selected contacts. P8 thought that “Reports is a great feature,” because the user “can decide what I am going to let them know. I am not going to let them know about my diet because I had a lot of bacon.” P6, P7, P8, and P10 thought that MS Friends is a nice and “straightforward” (P10) feature, on which P6 commented:

“I really like the idea that they can connect with people with MS.”

P6 liked having the RPM via Bluetooth in Vitals. Games were “clear and easy to find” to P6 and “very simple” to P10. P8 thought that “this is going to be very cool. I like the News.”

P6 commented on the overall design of the app:

“I like it. I like the nice simple design with large icons. It is easy to read. It has very nice feeling about so that I want to use it. It is nice. It looks like it can be useful.”

P7 thought of MS Assistant as a consistent app with a great display:

“From UD perspective, it is really well done.”

P8 thought that MS Assistant “is very well designed,” it offers flexibility and a choice, and further commented:

“I think this is fabulous. Enormous utility. It is incredibly thought out. I love this.”

P9 liked Home button and thought that the app was “very consistent” and “for someone with learning cognitive disability, it is accessible,” and added:

“This is better than most apps that I have experienced. I am impressed.”

4.2.1.3 Design Implications

As expected, audio transcripts revealed some additional usability problems reported by the participants and the existing problems were reported by a larger number of participants verbally, except in the case of the issues with the color contrast.

Overall, the main usability problems were labeling of the buttons, use of Next and Back buttons for the linear navigation, design of a number of UI elements, lack of page scrolling with the use of a keyboard, layout of a number of the buttons, certain feature requests, miscategorization of a number of labels, and navigation related to the design of the buttons and pages. For example, problems with the labels for “Education,” “Emergency,” “Input,” and “Output” buttons were reported by a majority of the participants (Appendix D). Labeling of the “Speech” button was reported by 40% of the participants and labeling of the “Energized” button on the Mood page was reported by 20% of the participants. Additionally, participants commented unfavorably on the use of Next and Back buttons for the linear navigation. However, they understood that the linear navigation using these two buttons might be more usable for the aging population of users. Moreover, they acknowledged that the smart interface and an option to switch from novice to expert user skips this way of the navigation for the more tech-savvy users. Design of certain UI elements was reported as well. For example, Profile and Settings did not look like buttons and the slider needed to be redesigned to half of the participants. Thirty percent of participants reported that Header looked like a button and that certain icons needed to be redesigned. Additionally, half of the participants reported that the page scrolling should be present while using the keyboard. Sixty percent of participants reported that the layout of the buttons needed to be changed (e.g., locations of Email Reports and View Reports buttons should be switched). Additionally, 40% of them thought that the spacing between the top buttons (e.g., Manual input button in Vitals, Week, Month, Year buttons in Reports) and the buttons bellow should be increased. Total of 30% of participants thought that after missing to fill out all the fields on one page, the prompt that follows should give them two options. First, it should let them go back to the previous page to fill out the missing content. Alternatively, it should allow them to go to the following page and leave certain fields empty. 20% of the participants stated that the font size of the MS News articles was small. In addition, 20% of the participants reported on the UDMIG v.2.1 questionnaire only that it was not clear that they can navigate through the whole interface in a linear fashion using the Next and Back buttons.

There was a number of problems that were found on the audio transcripts, which were not reported on the questionnaire. For example, 60% of participants thought that the app would benefit from the additional features (e.g., a place to specify the body area in Difficulties, the user's current weight with the text "This is what your weight is right now" in the weight goals, a lauder sound feedback with the use of the buttons, etc.). Miscategorization of certain labels was a problem to half of the participants. Sixty percent of the participants reported problems with navigation due to the lack of direction, page design, and multiple selections. Additionally, 20% of the participants reported a lack of consistency on a page layout due to two pages with multiple selections within Reports.

Moreover, there was a number of problems that were reported by only one participant. For example, labeling of "News," "Diary," and "Do not show this again" was not clear to 1 participant per label. These problems were not addressed in the app redesign section, except for the "Do not show this again" button, which was renamed into "Hide this page." Design of UI elements category had the additional problems with a design of an input field for the MS type in Personal Information within the Profile (n=1). Problem with the keyboard spell check was not present in the audio transcripts, and it was reported by 1 participant on a questionnaire. One participant reported that the interface requires too many clicks. Although the app provides an on-screen verification within the input field, the lack of it was reported by 1 participant. Additionally, lack of confirmation of activity was reported once.

4.2.1.4 Discussion

The results of the expert review confirm the effectiveness of the UDMIG v.2.1 within the application to MS Assistant. Overall, this implementation of the guidelines to the design of the mobile app scored well. Most of the participants favorably agreed that the guidelines were effective. Ninety percent of the mean values of the participants' ratings were equal to 4 or higher. In addition, there was a small number of recommendations related to the minor usability problems in MS Assistant. Design changes addressed the usability-related suggestions made by the expert reviewers.

4.2.2 Redesign of MS Assistant

MS Assistant was redesigned based on a small number of recommendations of expert reviewers related to the minor usability problems found in this mHealth app. Minor design changes addressed the usability-related suggestions made by the expert reviewers.

4.2.2.1 Design Changes

I summarized all the design features and related characteristics that needed to be redesigned based on the identified usability problems in both the UDMIG v.2.1 design criteria questionnaire and audio transcripts (Table 39). The rationale for the design response was to make a design change if in agreement with UDMIG v.2.1, if at least two participants reported the problem with the specific design feature, and if the suggestions were not already present in the prototype of MS Assistant. For the number of participants in Table 39, the larger number reported by either the analysis of audio files or the UDMIG v.2.1 design criteria questionnaire was used. In this way, the total number of participants reporting a problem was listed.

Table 39 – Design changes based on the identified problems with the design features and characteristics through both the UDMIG v.2.1 design criteria questionnaire and audio transcripts

Design Feature and Related Characteristic		**Number of Participants, N**	**Design Response**	**Design Changes**
Background, Contrast		N=3	Increase contrast	Grey was changed into white with black and green text on instruction pages.
Next and Back buttons, Navigation		N=7	No change	No change was made due to the design criteria IC2d. (i.e., Have more than one way to go to different pages while keeping the consistency). Next and Back buttons are typical of linear navigation.
Buttons, Labeling	Education	N=7	Change labeling: Education	“Education” was renamed into “Resources”.
	Emergency	N=7	Change labeling: Emergency	“Emergency” was renamed into “Emergency Contacts”.
	Energized	N=2	Change labeling: Energized	“Energized” (in Mood) was changed into “Excited”.
	Input, Output	N=7	Change labeling: Input, Output	“Input” was renamed into “Speech Input”, “Touch” into “Touch Input”, and “Output” into “Display and Sound”.
	Speech	N=4	Change labeling: Speech	“Speech” was renamed into “Voice”.
	Do not show this again	N=1	Change labeling: Hide this page	“Do not show again” button was renamed into “Hide this page.”
	Diary	N=1	No change	No change was made due to the small number of participants reporting the problem.
	News	N=1	No change	No change was made to “News” due to the inconsistency with other button labels within “Resources.”
UI elements, design (form and color)	Profile, Settings	N=5	Redesign Profile and Settings buttons	Name of the app, MS Assistant, was taken out of the Home page top navigation bar, and the icons for Profile and Settings were added.
	Header	N=3	Redesign header	Black color of the icons for the current state was changed into the color of that function (e.g., Diary icon in green, Reports icon in blue, etc.).
	Slider	N=5	Redesign slider	Numbers on the slider were placed on the top of it.
	Icons	N=3	Redesign icons	Voice icon was replaced with former Output icon, and Speech Input icon with former Speech icon. Display and Sound icon and Seeing icon (in Difficulties) were redesigned.
	MS type	N=1	No change	No change was made due to problems that drop-down menu causes for people with limited dexterity, similar to the use of the picker.
Buttons, Layout		N=6	Change the layout	View Report button was moved above the Email Report button. Names of the VR games were shortened. The other changes were not made due to the inconsistencies.
Button spacing, Layout		N=6	Increase spacing	A spacing between the top buttons and large buttons bellow was increased.
Keyboard, Page scrolling		N=5	Add page scrolling w/keyboard	Page scrolling was added with the use of a keyboard.

Table 39 – Design changes based on the identified problems with the design features and characteristics through both the UDMIG v.2.1 design criteria questionnaire and audio transcripts *(Continued)*

Design Feature and Related Characteristic	**Number of Participants, N**	**Design Response**	**Design Changes**
Prompt, Content	N=3	Redesign prompt	Prompt was redesigned to inform about the missing data and to allow the navigation to the following page without having to fill out all information.
Buttons, Haptic feedback	N=3	No change	iPhone 6 does not have the Taptic Engine that provides the vibration.
System, Navigation	N=2	Add text to the first instruction page	Text about the navigation and using Next and Back buttons was added to the first instruction page.
Text, font size	N=2	Increase font size	The font size of the MS News articles was increased.
Buttons, Single tap	N=1	No change	No change was made due to the design criteria IC13a (i.e., Use a single tap throughout the app instead of double-clicking).
Keyboard, spell check	N=1	Provide spell check w/keyboard	Spell check was provided within the keyboard.
Feature, Feature request	N=6	Add information about a MS friend	Information about MS Friends was added on the calling page. No other changes were made due to the small number of participants reporting the specific problem (N=1 per problem).
Labels, Miscategorization	N=5	No change	No changes were made due to the small number of participnats reporting the specific problem (N=1 per problem).
Page layout, Lack of consistency	N=2	No change	No change was made to the second page of Reports due to the lack of page space.
Keyboard, On-screen verification	N=1	No change	No change was made since the on-screen verification exists within the input field.
Buttons and pages, Navigation	N=6	No change	No changes were made to the small number of participants reporting the specific problem (N=1 per problem).
Lack of confirmation of an activity, Navigation	N=1	No change	No change was made due to the small number of participants reporting the problem.

Dark grey background on the instruction pages was changed into white to provide more contrast against the black and green (i.e., confirmation) text and “Do not show this again” was renamed into “Hide this page” (Figure 16) Even though only 1 participant reported a problem with the “Do not show this again” button text and design, I changed it to reflect the more familiar visualization of the hiding of certain pages commonly used in the user interface design with the X sign for closing the page. “Education” was renamed into “Resources”, “Emergency” into “Emergency Contacts” (Figure 17), “Energized” (in Mood) into “Excited” (Figure 21), “Input” into “Speech Input”, “Touch” into “Touch

Input", "Output" into "Display and Sound" (Figure 18), and "Speech" was replaced with "Voice" (Figure 19).

Due to the lack of space on the top navigation bar, the name of the app, MS Assistant, was taken out of the Home page and the icons for Profile and Settings were added (Figure 17). The color of the icons for the header (e.g., Diary, Reports, etc.) was

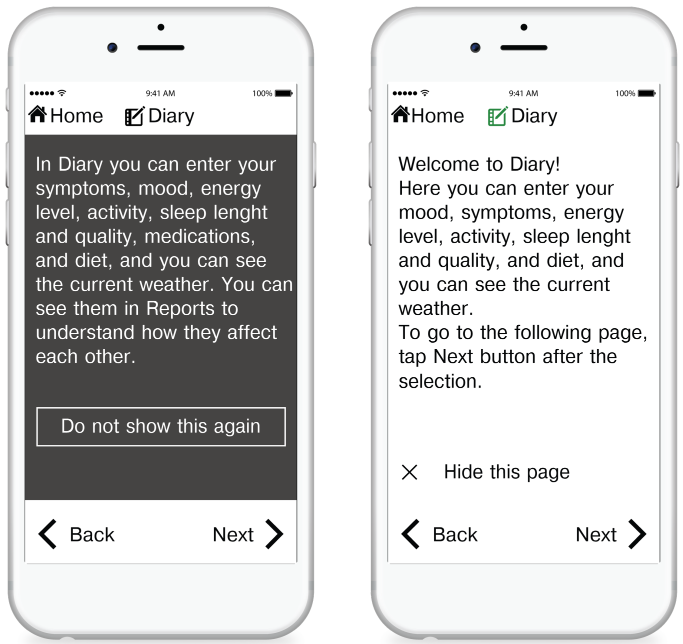


Figure 16 – Diary Instruction page: before (left) and after (right)

changed from black into the color of that function (e.g., Diary icon in green, Reports icon in blue, etc.). In this way, the icon and the header look like the part of the page background and not like the buttons (Figure 16, Figure 18, Figure 20). Numbers on the slider were placed on the top of it on the Symptoms, Difficulties, and Activity pages. Voice icon was replaced with the former Output icon (Figure 19), and Speech Input icon with the former Speech icon.

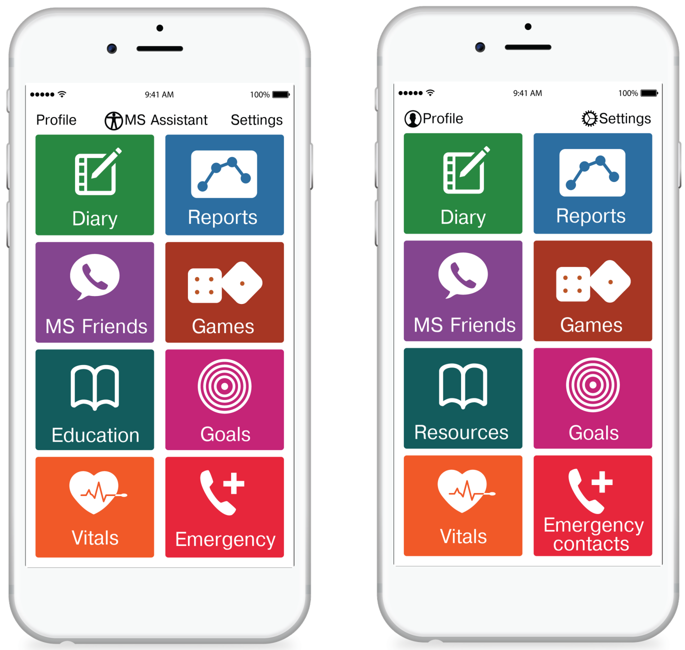


Figure 17 – Home page: before (left) and after (right)

Even though only one participant reported that there was no spell check with the use of a keyboard, this general feature was implemented because it is present in a majority of the apps. Page scrolling was added with the use of a keyboard.

A prompt in Personal Information within Profile feature appeared in a case the user did not (want to) fill out all information on the page. It was redesigned to inform about the missing data in a way that allows users to go to the following page without having to fill out all information (i.e., "Do you want to fill out the missing information?" with Yes that takes them back to the previous page, and No that takes them to the following page). Text about the navigation (i.e., linear navigation using Next and Back buttons) was added to the first instruction page within Diary feature (the system, navigation) (Figure 16).

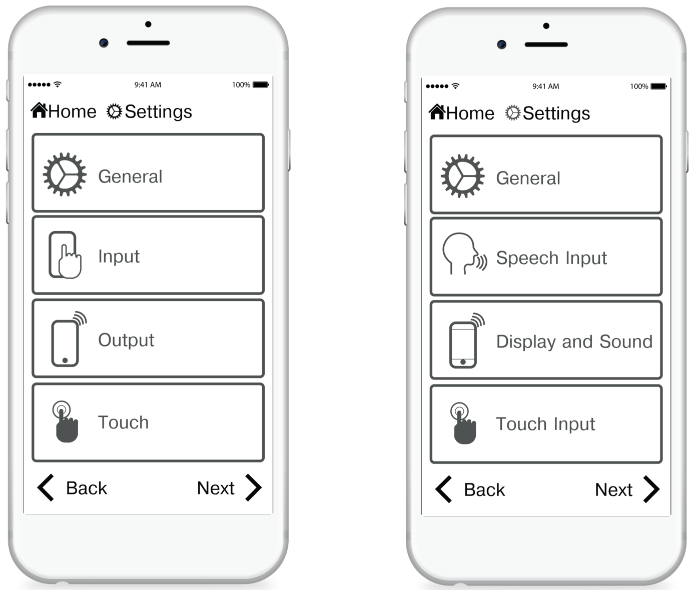


Figure 18 – Settings page: before (left) and after (right)

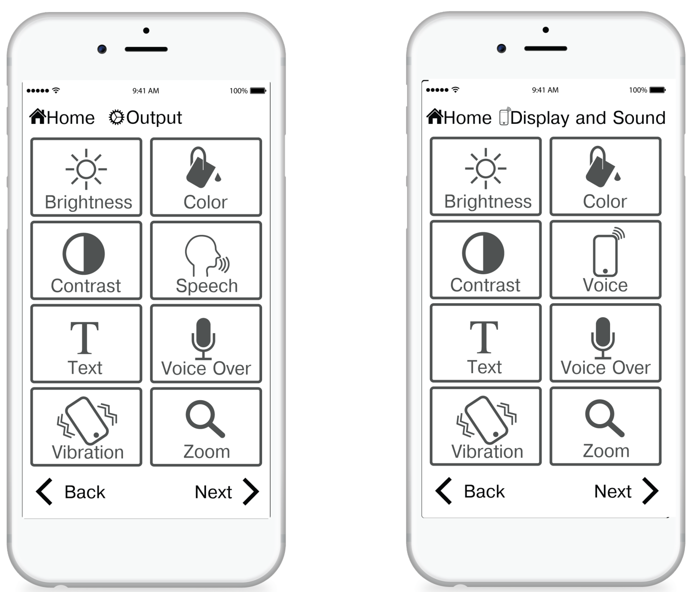


Figure 19 – Display and Sound page: before (left) and after (right)

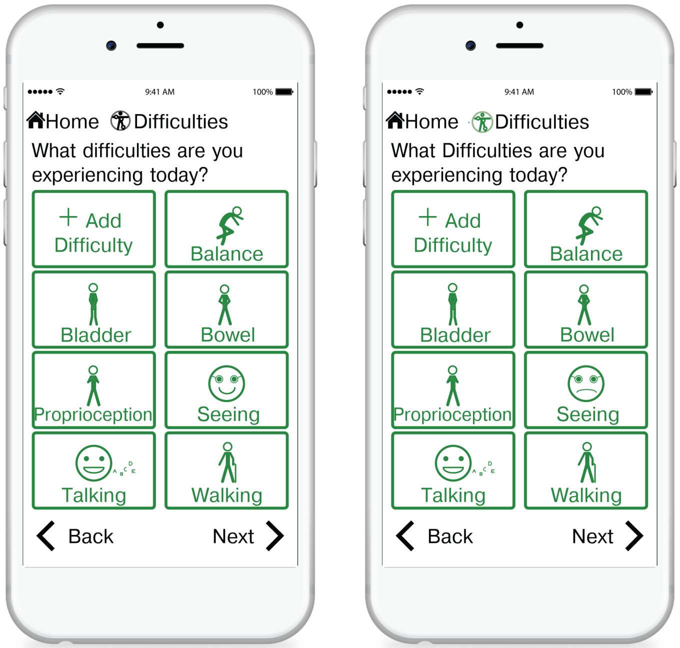


Figure 20 – Difficulties page: before (left) and after (right)

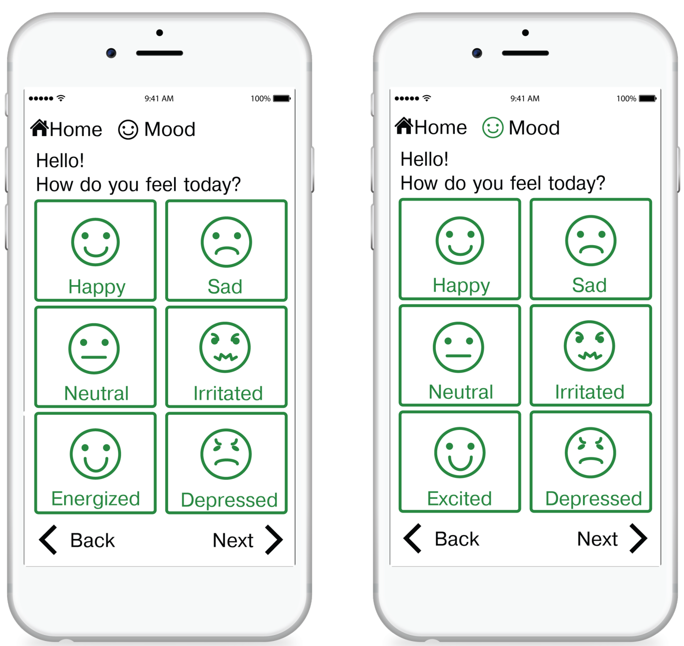


Figure 21 – Mood page: before (left) and after (right)

The font size of the MS News articles was increased to the font size of 12.5 to allow for a decent amount of text presented on one page.

The layout of the buttons was changed (e.g., View Report button was moved above the Email Report button, and the names of the VR games were shortened). The other layout changes were not made due to the inconsistencies with the page layout.

A spacing between the top buttons and large buttons below (e.g., Manual entry, and Week, Month, Year buttons) was increased.

There was a number of feature requests. For example, additional information about MS Friends is added on the calling page (e.g., friend's interests, MS type, and other information the person wants to share) (Figure 22). No changes were made to the other feature requests due to the small number of participants reporting the problem (N=1 per problem).

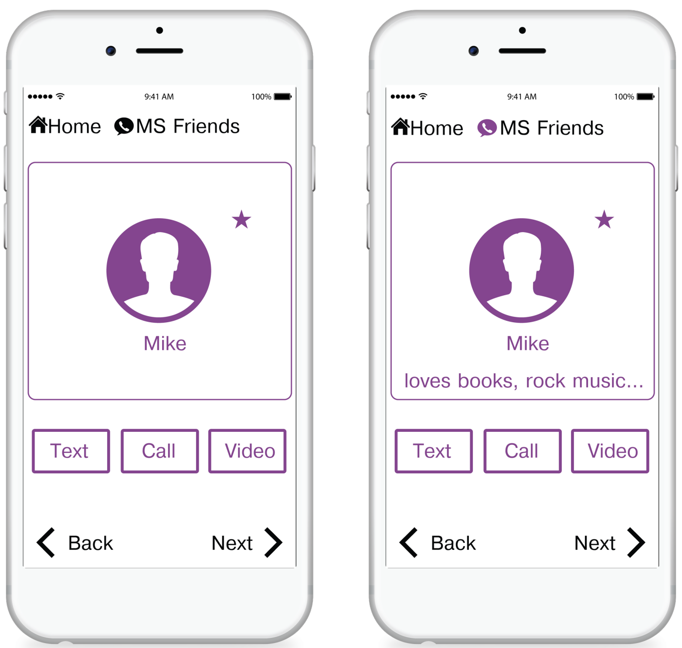


Figure 22 – MS Friends calling page: before (left) and after (right)

There were 7 participants reporting a problem with the navigation using Next and Back buttons. However, no change was made due to the design criteria IC2d. (i.e., Have more than one way to go to different pages while keeping the consistency). Next and Back buttons are typical of linear navigation and will be used in the novice user mode only. Additionally, 3 participants reported problems with the lack of the tactile feedback, which was not incorporated because iPhone 6 does not have the Taptic Engine that provides the vibration while tapping the buttons that was included in later versions. The total number of participants reporting the problems with the miscategorization of the labels was 5. However, no changes were made due to the small number of participants reporting the individual problem (N=1 per problem). No change was made to the second page of the Reports due to the lack of page space (N=2). Additionally, no change was made to the on-screen verification while using a keyboard because the verification existed within the input field (N=1). Even though was there was a total of 6 participants who reported a problem with the navigation due to the design of the buttons and pages, no changes were made due to the small number of participants reporting the specific problem (N=1 per problem). Lack of confirmation of an activity on a Symptoms page was reported by 1 participant. The change was not made due to the perseverance of the consistency within the Diary pages.

4.2.3 Usability Testing with Individuals Aging with MS

Usability testing of MS Assistant with individuals aging with MS was conducted to assess the usability of the mHealth app to determine the effectiveness of UDMIG v.2.1 in producing a universally usable product. I collected user outcome measures, such as the ratings of the effectiveness of the application of the UDMIG design criteria to the app, completion rates, number and types of errors, number and types of help requests, and satisfaction ratings to assess the usability of the app. Additionally, I collected all verbally identified usability problems during the administration of the “talk aloud” protocol and categorized the data into the common themes to determine the main issues with the app. This was a second assessment of the guidelines as a part of the iterative evaluation process following the expert review.

4.2.3.1 Methods

I tested the effectiveness of the design elements in MS Assistant, the effectiveness of the mHealth application, and the satisfaction with the app with the purpose to validate the UDMIG v.2.1, by conducting the usability testing with the end-user population. Usability testing was undertaken in a controlled environment, CATEA's Usability Lab, and in participants' homes using the same equipment.

4.2.3.1.1 Participants

Following the recommendations for the sample size in usability testing when collecting quantitative usability metrics (Nielsen, 2006), total of 22 individuals diagnosed with MS was recruited. Participants were recruited through the TechSAge Participant Registry at Georgia Institute of Technology and snowball sampling. The inclusion criteria for the study were that participants be at least 18 years of age and diagnosed with MS at least 5 years ago.

The characteristics of the participants are presented in Table 40. There were 17 right-handed, 4 left-handed, and 1 ambidextrous participant.

Table 40 – Characteristics of the participants

Female	**Male**	**Age range (years)**	**Mean age (years)**	**Number of years diagnosed with MS**
19	3	39-68	52.57 ± 9.20	19.36 ± 9.45

The background questionnaire was administered where participants self-reported their number and types of functional limitations (Figure 23, Table 41).

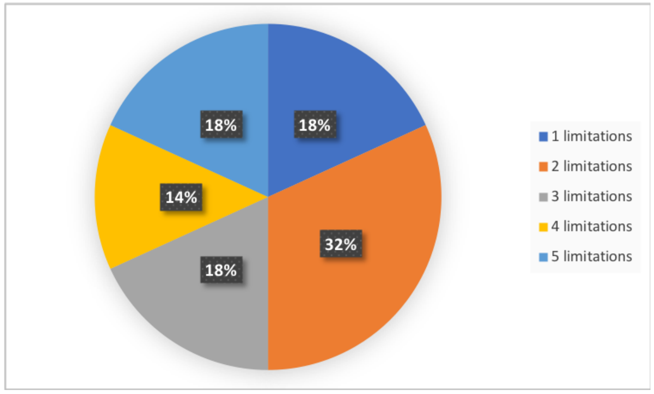


Figure 23 – Number of self-reported functional limitations in participants

Table 41 – Types and number of functional limitations in participants

Functional limitations	**Number of participants reporting the limitation**
Cannot walk	9
Cognition	6
Fatigue	6
Dexterity	5
Difficulty Walking	4
Vision	3
Balance	3
Gait	3
Tremor	3
Muscle spasm	2
Muscle Weakness	2
Motor functions	1
Paraplegic	1
Problems with writing	1
Foot drop	1
Numbness (left leg)	1
Cannot sit up	1
Cannot stand	1
Cannot lift leg	1
Cannot use left hand	1
Nerve pain (trigeminal neuralgia)	1
Neuro bowel/bladder	1
Problems with heat	1

4.2.3.1.1.1 Touch Screen Experience

One out of 22 participants reported no experience with the use of touchscreen devices. The other 21 participants self-reported their touchscreen experience on a scale from 1 = none, 2 = novice, 3 = intermediate, 4 = advanced, to 5 = expert. The level of touchscreen experience ranged from 1 to 5, with the mean of 3.90 ± 1.30.

4.2.3.1.1.2 Use of mHealth and MS-specific Mobile Applications

I asked the participants to rate their use of mobile apps (e.g., Weather Underground: Forecast ("Weather Underground: Forecast," 2017), Skype ("Skype for iPhone," 2017)), mHealth apps (e.g., iHealth, Health ("Health," 2017)), and MS-specific applications (e.g., *My MS Manager*, *MS self*) on a scale from frequently (e.g., a few times a day), often (e.g., once a day), occasionally (e.g., once or twice a week), very infrequently (e.g., once a month), to never (Table 42).

Table 42 – Use of mobile, mobile health, and MS-specific applications in participants

	Frequently	**Often**	**Occasionally**	**Very infrequently**	**Never**
Use of mobile apps	17	2	1	1	0
Use of mobile health apps	3	2	5	6	5
Use of MS-specific mobile apps	2	0	4	4	11

Overall, the majority of the participants reported frequent use of mobile apps, less frequent use of mHealth apps, except for 3 participants who reported frequent use of these apps and 2 who reported they often use these apps, and even less frequent use of MS-specific apps, except for 2 participants who reported they frequently use this type of apps. Five participants self-reported they never use mHealth apps, and 6 use them very infrequently. Eleven participants reported they never used MS-specific app, and 4 used them very infrequently.

4.2.3.1.2 Testing Devices

MS Assistant app was tested on an iPhone 6 device. iPhone 6 has Retina HD display that is 4.7 inches in size with a 16:9 resolution of 1334x750 (326 ppi). Mr. Tappy ("Mr. Tappy," 2018), a kit for recording mobile devices from a user's point of view, was used to record the user interaction with the mHealth app. Camtasia ("Camtasia," 1995 - 2018), and ScreenFlow ("ScreenFlow," 2018), screen recording software designs, were used to record the interaction of the participants with the app while using the app with Mr. Tappy.

4.2.3.1.3 Outcome Measures

There are three types of outcomes that I measured: effectiveness of the design features, the effectiveness of the app, and satisfaction with the app.

To measure the effectiveness of the design features in MS Assistant, the *ratings* of *the design features* and the application of related design criteria to the mHelath app on a scale from 1 to 5 (from 1 – strongly disagree to 5 – strongly agree) were collected with the purpose to evaluate the UDMIG v.2.1.

To measure the effectiveness of the mHealth app, *completion rates* were calculated and reported by counting the number of tasks completed successfully. The task was defined as successful if the participant did not ask for help to finish it. In addition, the usability issues were observed by looking at the recorded video files. Logs were used to calculate *the number of errors*, including *the number of help requests* (i.e., assists). After importing all the recorded video files, I marked all *the usability problems* related to slips, mistakes, and help requests that were observed or stated by the participants.

To measure satisfaction with the app, SUS was used as a 10-item questionnaire assessing perceived ease of use (Sauro, 2011). Each item is rated on a scale from 1 (strongly disagree) to 5 (strongly agree). *The SUS score* was calculated using the score contributions from each item ranging from 0 to 4. The sum of the scores was multiplied by 2.5 to convert the range of possible values from 0 to 100 and obtain the overall SUS score (Sauro, 2011).

4.2.3.1.4 Procedures

Participants signed the informed consent form approved by the Georgia Tech IRB. They completed a demographic background questionnaire reporting their age, gender, number of years diagnosed with MS, functional limitations, and left- or right- handedness. Participants rated the usage frequency of mobile, mobile health, and MS-specific applications (ranging from frequently, often, occasionally, very infrequently, to never), and touchscreen experience (on a scale from 1 = none, 2 = novice, 3 = intermediate, 4 = advanced, to 5 = expert).

The participants then performed the set of ten tasks on MS Assistant (Table 43). Ten performed tasks included self-reporting the health and wellness data (e.g., mood, symptoms and related difficulties, energy level, activities, sleep length and quality, and diet), emailing the reports to the healthcare provider, calling a friend diagnosed with MS, exploring the VR games, reading the MS news, setting up the weight goal, manually inputting the blood pressure, calling the healthcare provider, entering the personal information, and changing the text size (customizing the visuals). The participants were given the health and wellness data they should populate. See Appendix E for the complete description of the tasks.

Table 43 – Study tasks that users performed during the usability testing

Study Tasks
1. Enter health and wellness data
2. Email reports
3. Call MS friend
4. Find virtual reality games
5. Read the MS news
6. Set up the goals
7. Measure your blood pressure
8. Call your healthcare provider
9. Enter your personal information
10. Customize visuals (text size)

They were asked to complete each task accurately and to ask for help when they cannot find a solution to finish the task. Following the completion of the tasks, participants were asked to rate their satisfaction with the app using the System Usability Scale (SUS) (Sauro, 2011). In addition, they evaluated the usability and equitability of the mobile application by rating the UDMIG v.2.1 design criteria on the Likert scale from 1 = strongly disagree, to 5 = strongly agree. Finally, the participants evaluated the utility of the app by rating usefulness and importance of the functional features in MS Assistant on a 5-point scale (from 1- not useful at all to 5 – very useful, and from 1- not important at all to 5 – very important, respectively).

The usability study was video recorded using Mr. Tappy kit and a screen recorder. It lasted from 60 to 120 minutes. All participants were compensated $20.00 for their time and $5 for the travel to Georgia Tech.

4.2.3.2 Results

The results reporting the effectiveness of the design features in MS Assistant, the effectiveness of the mHealth app, and satisfaction with the app are detailed in this section.

4.2.3.2.1 Effectiveness of the Design Features

Ratings of the design features as those were applied to the design of the mobile app following the UDMIG design criteria are reported.

Twenty-two participants rated 45 items on the questionnaire. The total number of responses was 990, with 1 rating missing. Rating of 3 (i.e., neither) was given for the missing value.

The mean of all the ratings for the design criteria is within a range of 4.05 – 4.86 (Table 44). Frequency of 4 and 5 ratings, which is a percentage of 4 and 5 ratings per design feature, was 77.27% - 100%. The design criteria DE2b (i.e., This application provides system feedback for my actions, such as a beep when pressing a key or an error message for an invalid input value) had the lowest mean of the ratings equal to 4.05. Participants who rated these design criteria low did not notice the sound when tapping (clicking) on the buttons. However, the volume was turned on, and the clicking sound was present.

Table 44 – Mean ratings (with standard deviations) of the design features

Design Elements Guidelines	**Ratings, Mean, M**	**Ratings, Standard Deviation, SD**	**Frequency of 4 and 5 ratings, F (%)**
1.a. Large enough button size.	4.68	0.78	90.91%
1.b. Good contrast between the background colors against the images and text.	4.59	0.73	86.36%
2.a. A feedback about a confirmation of my activity and a current state.	4.27	0.94	77.27%
2.b. System feedback for my actions, such as a beep when pressing a key.	4.05	1.29	77.27%
2.c. Text description for each icon.	4.68	0.78	90.91%
2.d. Obvious feedback (visual, audio, and/or tactile) when a target is selected.	4.68	0.48	100%
3. Alternate methods of input and use, such as speech input (e.g., Siri, Voice Control).	4.50	0.80	81.81%
4.a. Visible and easily accessible frequent and important actions.	4.64	0.66	90.91%
4.b. Text warnings as opposed to symbols and icons.	4.41	1.10	77.27%
4.c. Buttons in colors that stand out, and arranged in linear order.	4.77	0.53	95.45%
5.a. Different modes of feedback, such as sound or vibration.	4.41	0.80	81.81%
5.b. Redundant visual presentation of essential information (e.g., color, icons, and text).	4.45	0.96	90.91%
6.a. Easy reversal of my actions if I make a mistake, such as “Are you sure you want to send the reports to the selected contacts?”, with reversion back to the contacts screen when I press “No”.	4.59	0.67	90.91%
6.b. The system which can detect the error and offer a prompt message for handling it.	4.5	0.96	90.91%
Interface Structure Guidelines			
1.a. The same means of use for all users, by eliminating specialized design and language.	4.14	0.77	77.27%
1.b. One hardware and software application for all users that allows individualized preferences.	4.68	0.65	90.91%
2.a. The same design elements for the navigation from page to page.	4.77	0.43	100%
2.b. Navigation assistance (e.g., menu, instructions) for how to navigate to specific points in the system, which includes navigation to the home page and to any relevant page.	4.55	0.67	90.91%
2.c. Specific, clear, and evident instructions, which can be disabled.	4.55	0.80	90.91%

Table 44 – Mean ratings (with standard deviations) of the design features *(Continued)*

Design Elements Guidelines	**Ratings, Mean, M**	**Ratings, Standard Deviation, SD**	**Frequency of 4 and 5 ratings, F (%)**
Interface Structure Guidelines			
2.d. More than one way to go to different pages while keeping the consistency.	4.23	0.75	81.81%
3.a. Standardized format and consistent location of target items within.	4.68	0.57	95.45%
3.b. Identical terminology in prompts, menus, and help screens.	4.45	0.80	90.91%
4.a. The use of the picker is avoided.	4.55	0.80	90.91%
4.b. Scrolling text, especially horizontal formats, is avoided.	4.68	0.57	95.45%
5.a. Clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games).	4.82	0.39	100%
5.b. Related information in a group, and the most frequent operations highest on the page.	4.32	0.78	81.81%
5.c. Clear understanding of which button is selected and what are the consequences of my action.	4.68	0.57	95.45%
6.a. Large enough and legible fonts whenever possible.	4.77	0.43	100%
6.b. Good structure (e.g., grammar) in written text.	4.59	0.67	90.91%
6.c. Video conferencing in addition to talking on a phone.	4.59	0.80	90.91%
6.d. Cursive and decorative fonts and use of all uppercase letters are avoided.	4.73	0.46	100%
7.a. Understandable reading level of text material.	4.86	0.35	100%
7.b. The use of technical language is avoided.	4.73	0.46	100%
8. A choice of linear navigation vs. random access.	4.59	0.67	90.91%
9. Personalization to change my skill level from a “novice” to an “expert” user.	4.50	0.80	81.81%
10.a. Configuration of the display settings to my needs and preferences, such as text size, contrast.	4.82	0.39	100%
10.b. Configuration of the brightness, speech input and output, and similar in settings.	4.68	0.57	95.45%
11. Aesthetically plausible color scheme.	4.77	0.43	100%
12. Main navigation buttons of equal importance accessible for me.	4.73	0.46	100%
13.a. Use of a single tap throughout the app instead of double-clicking.	4.82	0.39	100%
13.b. Minimized steps (i.e., basic tasks) when possible.	4.55	0.60	95.45%
14.a. Visible spacing between the small buttons.	4.55	0.60	95.45%
14.b Zero or small spacing between the large buttons.	4.68	0.57	95.45%
14.c. The location of the buttons near the center or the bottom of the screen.	4.73	0.46	100%
15. Main navigation buttons of equal importance at the bottom of the screen.	4.77	0.43	100%

Out of a total of 990 ratings, 69.29% (n=686) of the design criteria were rated as a 5. An additional 22.72% (n=225) were rated as a 4, 6.67% (n=66) were rated as 3, 0.81% (n=8) were rated as 2, and 0.51% (n=5) were rated as a 1.

The mean values of the ratings were 4.05 and above. Therefore, participants rated all design features highly in MS Assistant.

Design feature represented by DE2b "system feedback for the actions, such as a beep when pressing a key" was rated the lowest because some participants did not hear the sound (N=5) and rated it very low (rating=1, N=2; rating=2, N=1; rating=3, N=2). The second lowest rating was for the design feature characterized by IC1a "the same means of use for all users, by eliminating specialized design and language" (M=4.14). There were five participants who rated this feature as 3 and the others rated it as 4 and 5. Rating of 3 was given when participants were not sure how to rate the feature. The next lowest mean rating was equal to 4.23 and was given to IC2d: "more than one way to go to different pages while keeping the consistency." Four participants rated it as 3 because they did not realize that they can navigate through the interface using both random access and linear navigation. Mean rating of 4.27 was given to DE2a "feedback about a confirmation of my activity and a current state" because five participants rated it low due to an initial lack of understanding of the script (rating 2, N=1; rating=3, N=4). Mean rating of 4.32 was given to IC5b "related information in a group, and the most frequent operations highest on the page" because 4 participants who gave the rating of 3 could not recall the layout of the page and were not clear how to rate the feature.

All other design features were rated very highly (M=4.41 and above). The highest mean rating was given to IC7a "understandable reading level of text material" (M=4.86). The next two highest ratings (M=4.82) were given to IC13a "use of a single tap throughout the app instead of double-clicking," IC10a "configuration of the display settings to my needs and preferences, such as text size, contrast," and IC5a "clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games)."

The difference between the lowest mean rating (M=4.05) for DE2b and the highest mean rating (M=4.86) for IC7a was statistically significant ($t(21)=3.015$, $p=.007$). However, the sound feedback after pressing a key is a smartphone device system feature, and it cannot be addressed from the design point. The second lowest mean rating (M=4.14) for IC1a and the highest mean rating (M=4.86) for IC7a were significantly different as well ($t(21)=4.403$, $p<.001$). However, even though five participants rated these features as 3 and realized that it makes the app distinguishable, all participants, including those five, wanted to have MS displayed on the main app icon. The next lowest mean rating (M=4.23) for IC2d and the highest mean rating (M=4.86) for IC7a were significantly different ($t(21)=3.853$, $p<.001$). This suggests that there is a room for improvement of the IC2d "more than one way to go to different pages while keeping the consistency." The mean rating (M=4.27) for DE2a and the highest mean rating (M=4.86) for IC7a were significantly different ($t(21)=3.095$, $p=.005$). It does not need a redesign because the low ratings were due to the lack of understanding of the script. The difference between mean rating of 4.32 that was given to IC5b and the highest mean rating (M=4.86) for IC7a was statistically significant ($t(21)=3.206$, $p=.004$). Four participants who rated it as 3 could not initially understand how to rate this feature.

Among the 22 participants, mean ratings ranged from 3.89 – 4.98. The participant with the lowest overall mean of the ratings (M = 3.89) did not give a rating higher than 4 to any individual criterion, with 40 rated as 4 and 5 rated as 3. All other 21 participants' average ratings were 4.07 or above.

4.2.3.2.2 Effectiveness of the app

Video transcripts were analyzed to report *completion rates*, *number of errors*, *number of help requests*, and verbally expressed *usability problems*.

Total of 22 participants completed 10 tasks each (22 participants x 10 tasks = 220 tasks). *Completion rates* were calculated and reported by counting the number of tasks completed successfully without asking for help (M = 76.82%, SD = 20.79%; range = 40% to 100%). Two participants had the lowest completion rate of 40%, and another two have completed 50% of the tasks without asking for help. One of the two participants with the lowest completion rates was asking for help whenever unsure about the next step, which resulted in the largest number of help requests (n = 23) and the low completion rate.

In addition, video recordings were used to calculate the number of errors and the number of help requests. Total *number of errors* participants made was 205 (M = 9.32, SD = 7.66; range = 0 to 32), and an additional total number of help requests was 101 (M = 4.59, SD = 5.92; range = 0 to 23). The participant with the largest number of errors (n = 32) was an older adult (age 66) who was the only one who did not have prior experience using the touchscreen devices. The third of their errors were due to the problems with the touchscreen and slips. By counting the number of errors based on the type of an error, and by categorizing those into the common themes, I identified all usability problems with the app that participants encountered during the interaction with the user interface (Table 45). Related design features and characteristics are reported based on the type of an error.

Table 45 – Usability problems with the app (i.e., themes), the description and the number of related errors with the number of participants and associated design features and characteristics

Usability problems	**Errors**						
Themes	**Error description**	**Design Feature and Related Characteristic**	**Ability Required to Perfom the Task**	**Number of errors, n**	**Mean, M**	**Standard Deviation, SD**	**Number of participants, N**
Navigation n=92	Confusion over where to go to enter new data	Home page and buttons, design	Cognitive	74	3.36	2.92	N=21
	Problem with understanding the use of the buttons	"Add ... " buttons, design		10	0.45	0.96	N=5
	Lack of understanding of the sequence required to navigate	Next and Back buttons, navigation		6	0.27	0.70	N=4
	Lack of understanding that double selection provides one page for each selection	Double selection, page design		2	0.09	0.29	N=2
Slips n=37	Slips	n/a	n/a	37	1.76	2.01	N=14
Slider n=26	Lack of understanding of how to use the slider	Slider, design	Cognitive	11	0.05	0.86	N=7
	Issues with the ease of use of the slider	Slider, design	Physical	11	0.05	0.80	N=7
	Problems with entering new data in the text box instead of the slider	Slider, design	Cognitive	4	0.18	0.85	N=1
Button design / Page layout n=13	Button looks like a title	“Manual Input”, design	Cognitive	8	0.36	0.49	N=8
	Icon looks like a clickable button	Icons (top navigation bar, friends, bp measurement), design		5	0.23	0.87	N=2

Table 45 – Usability problems with the app (i.e., themes), the description and the number of related errors with the number of participants and associated design features and characteristics *(Continued)*

Usability problems	**Errors**						
Themes	**Error description**	**Design Feature and Related Characteristic**	**Ability Required to Perfom the Task**	**Number of errors, n**	**Mean, M**	**Standard Deviation, SD**	**Number of participants, N**
Keyboard n=7	Missing to select the button on a keyboard due to its small size and a location	Done button (keyboard), small size and the location	Visual	5	0.23	0.87	N=2
	Missing the keys on a keyboard due to their small size	Keys (keyboard), small size		1	0.05	0.21	N=1
	Lack of understanding of how to use the keyboard	Keyboard, design	Cognitive	1	0.05	0.21	N=1
Font size n=4	Inability to see and understand the text	Prompt messages, small font size	Visual	4	0.09	0.43	N=3
Legibility of information n=1	Lack of clarity of information	Text descriptions, page design	Cognitive	1	0.14	0.35	N=1

The main issues with the mHealth app were problems with the navigation, slider, and the button design, including the page layout.

1. Navigation: The majority of the participants experienced the issues with the navigation. They were mostly confused about where to enter new data. The script asked the participants to enter mood, symptoms, energy level, sleep quality and duration, activities, and diet without telling them where to do it. I was testing the intuitiveness of the app's main functional feature (i.e., Diary), which had the purpose of collecting the self-reported and tracked health and wellness data. Besides the issue with finding where to enter mood and other health- and wellness-related data (n=17, N=12), participants encountered problems with knowing where to enter difficulty (n=6, N=3), find the MS news (n=4, N=4), measure the blood pressure (n=8, N=5), find the healthcare provider's contact information (n=7, N=4), enter the personal information (n=15, N=7), and change the text size (n=16, N=10). Five participants had a problem with understanding the use of "Add …" buttons (e.g., "Add difficulty," "Add game," "Add contact") (n=10). They were tapping on the "Add difficulty" button to enter difficulty walking (n=5, N=3), on "Add game" button to select a game (n=2, N=1), on "Add symptom" to add numbness (n=1, N=1) and to add difficulty walking (n=1, N=1), on "Add contact" to select a specific healthcare provider (i.e., Dr. N) (n=1, N=1).

Only four participants had problems with the lack of understanding of the sequence required to navigate through the app (n=6). They expected that when the selection is made (i.e., the button is pressed), the chosen page would open without having to tap on Next button. However, when I explained the reasoning for having the linear navigation and double selection using Next and Back buttons to them, they understood its importance. One of the participants suggested that Next button is removed, and Back is kept because they understood the importance of being able to navigate backward page-by-page.

Two participants experienced issues with the understanding that double selection provides one page for each selection. Specifically, when they selected both eggs and bread on breakfast page, participants expected to have both selections (i.e., eggs and bread) on the following page. However, the app was designed in a way that the first page provides the first selection, and the following page provides the second selection. The same design is applied when selecting multiple symptoms, difficulties, and activities.

2. Slider: The second issue with the app was the lack of understanding of how to use the slider and the problem with its ease of use (Figure 24). Seven participants had a problem to understand how to use the slider (n=11). Once they understood how to use it, the majority of them did not have any problems with the slider. The other seven participants had issues with the ease of use of the slider and experienced difficulty moving its parts to get the correct input value (n=11). Additionally, one participant had problems entering new data in the correct field (i.e., issues with changing time using the slider) (n=4). They used the comment section to enter data that were supposed to enter using the slider.

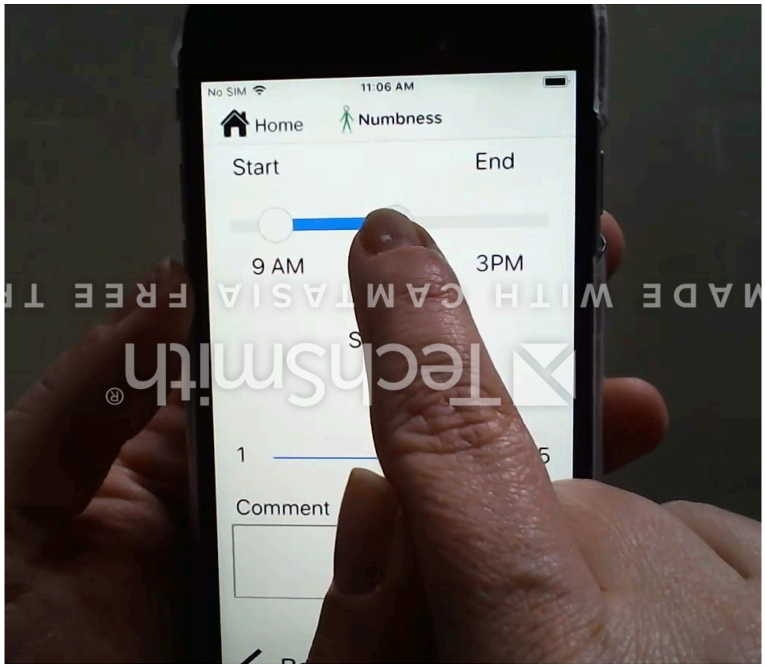


Figure 24 – The use of the slider

3. Button Design and Page Layout: The next usability problem was with the design of the buttons and icons and their location on the page relative to other design elements on the same page. Eight participants had problems understanding that "Manual Input" button is an actual button and not the title of the page. Its location at the top of the page and the large image that represents the use of the wireless blood pressure monitor made it confusing, and participants had problems to understand its function. In addition, the same image of the use of the blood pressure monitor looked like a clickable button to one participant (n=1). Moreover, one icon that represented a phone contact (n=1) and top navigation bars (n=3) looked clickable to three participants.

4. Other Errors: Other minor usability problems with the mobile app include the issues with the keyboard. The keys (n=1, N=1) and "Done" button (n=5, N=2) on the keyboard were found too small and caused six participants to make errors when using those features.

The only one participant who did not have prior experience with using the touchscreen devices had problems with understanding of how to use the keyboard (n=1).
Three participants had a problem with reading and understanding the information presented in the prompt messages (n=4) due to the small size of the prompt message and small font size. Lastly, one participant did not understand whether the current or the goal weight was required to enter in the goal weight (n=1).

Participants experienced a total of 37 slips. Researchers (Lewis & Norman, 1995; Reason, 1990) have distinguished between mistakes and slips. Norman (1986, p. 414) explains the difference:

> "The division occurs at the level of the intention: A Person establishes an intention to act. If the intention is not appropriate, this is a mistake. If the action is not what was intended, this is a slip."

For example, accidentally typing a wrong word is a slip. For the purpose of this study, slips are not going to be analyzed because those are not caused by the design of the interface and the features of the app.

In addition, I counted *the number of help requests* based on the reason for making those requests, and I categorized those issues into the common themes to identify the most important usability problems with the app (Table 46). The two participants (P8 and P17) with the highest number of assists asked for help 23 and 17 times, respectively. P17 was the only participant who did not have prior experience using touchscreen devices.

Table 46 – The most important usability problems with the app (i.e., themes), description, the number of related help requests, and the number of participants and associated design features and characteristics

Usability problems	**Help requests**						
Themes	**Help requests description**	**Design Feature and Related Characteristic**	**Ability Required to Perfom the Task**	**Number of errors, n**	**Mean, M**	**Standard Deviation, SD**	**Number of participants, N**
Navigation n=76	Confusion over where to go to enter new data	Home page and buttons, design	Cognitive	53	2.41	2.28	N=16
	Lack of understanding of the sequence required to navigate	Next and Back buttons, navigation		20	0.91	3.01	N=5
	Confusion over where to go after the prompt message	Prompt, design		3	0.14	0.35	N=3
	Lack of understanding that double selection provides one page for each selection	Double selection, page design		1	0.05	0.21	N=1
Slider n=11	Lack of understanding of how to use the slider	Slider, design		8	0.36	0.79	N=5
	Issues with the ease of use of the slider	Slider, design	Physical	3	0.14	0.47	N=2
Keyboard n=5	Missing to select the button on a keyboard due to its small size and a location	Done button (keyboard), small size and the location		2	0.09	0.43	N=1
	Lack of understanding of how to use the keyboard	Keyboard, design	Cognitive	3	0.14	0.47	N=2
Button design / Page layout n=4	Button looks like a title	“Manual Input”, design		2	0.09	0.29	N=2
	The design and layout of the page is confusing	Second page of Reports, design		2	0.09	0.29	N=2
Legibility of information n=1	Lack of clarity of information	Text descriptions, page design		1	0.05	0.21	N=1

The identified usability problems when participants requested help match a smaller number of the issues with the user interface that was identified by counting the errors they made while performing the tasks.

1. Navigation: The main usability problem with the app was navigation. There was a total of sixteen participants that requested help when they had problems with navigation. The same sixteen participants were confused about where to go to enter new data (n=54). They had issue with finding where to enter mood and other health- and wellness-related data (n=10, N=10), enter happy mood (n=1, N=1), find a report (n=1, N=1), find symptoms and sleep buttons on Report page (n=1, N=1), how to email a report (n=1, N=1), enter difficulty (n=4, N=4), find the MS news (n=10, N=10), measure the blood pressure (n=3, N=2), find the healthcare provider's contact information (n=2, N=2), enter the personal information (n=9, N=9), and change the text size (n=13, N=7). Out of sixteen participants, five of them had issues with the lack of understanding of the sequence required to navigate through the app (n=20). They asked for help when needed to go to the following page using Next and Back buttons. Three participants asked for help after the prompt message appeared and they got confused about the navigation (n=3). One participant requested help after not realizing that double selection on the page provides one page for each selected value (n=1).

2. Slider: The second usability problem that was identified was the issue with the slider. Five participants had problems with understanding how slider works (n=8), and two participants had difficulty using and moving the slider (n=3).

3. Other Errors: Three participants experienced problems with the keyboard (n=5). Two of them requested help due to the lack of understanding of how to use the keyboard (n=3) and one asked for help because of the small size and the location of "Done" button (n=2). Issues with the design of the buttons and the layout of the page caused 4 participants to request help (n=4). Two participants asked for an assist because "Manual Input" button looked like a title (n=2), and the other two asked for help due to the existence and the layout of the second page in Reports (n=2). Lastly, one participant had problem understanding the page information on the Bread page in Diet when they wanted to change the value of the calories, which should not be changed by the users (n=1).

4.2.3.2.2.1 User Feedback

Moreover, while using MS Assistant, participants verbally identified specific *usability issues,* and *positive aspects* of MS Assistant via "talk aloud" protocol administration and in some cases recommended possible design solutions.

4.2.3.2.2.1.1 Usability Problems

I categorized those issues into themes and reported related design features and characteristics to identify usability problems with the app (Table 47).

Table 47 – Usability problems with the app (i.e., themes), description, design features and characteristics

Themes	**Usability Problem Description**	**Design Feature and Related Characteristic**	**Ability Required to Perfom the Task**	**Number of Times the Problem was Reported**	**Mean, M**	**Standard Deviation, SD**	**Number of Participants, N**
Navigation n=67	Confusion over where to go to enter new data	Home page and buttons, design	Cognitive	45	2.05	2.13	N=17
	Lack of understanding of the sequence required to navigate	Next and Back buttons, navigation		16	0.73	1.24	N=9
	Problem with understanding the use of the buttons	"Add ... " buttons, design		3	0.14	0.47	N=2
	Lack of understanding that double selection provides one page for each selection	Double selection, page design		3	0.14	0.35	N=3
Feature request n=27	Missing features and related recommendations	Feature, Feature request	Cognitive/ Physical/ Visual	27	1.23	2.58	N=8
Slider n=9	Lack of understanding of how to use the slider	Slider, design	Cognitive	7	0.32	057	N=6
	Issues with the design of the slider	Slider, design	Physical	2	0.09	0.29	N=2

Table 47 – Usability problems with the app (i.e., themes), their description, and related design features and characteristics *(Continued)*

Themes	**Usability Problem Description**	**Design feature and related characteristic**	**Ability Required to Perfom the Task**	**Number of Times Problem was Reported**	**Mean, M**	**Standard Deviation, SD**	**Number of Participants, N**
Button design / Page layout n=9	Button looks like a title	“Manual Input”, design	Cognitive	3	0.14	0.35	N=3
	Icon looks like a clickable button	Top navigation bar icons, design		3	0.14	0.47	N=2
	Not clear if goal or current weight is requested	Text box title, design		1	0.05	0.21	N=1
	Lack of understanding of how to deselect the button	Button, design		1	0.05	0.21	N=1
	Inability to see the buttons	Button, small size	Visual	1	0.05	0.21	N=1
Labeling n=8	Button labels (naming) are not clear	Buttons, Labeling	Cognitive	8	0.36	0.66	N=5
Icons n=4	Issues with the design of the icons and related recommendations	Icons, design		4	0.18	0.50	N=3
Instructions n=4	Issues with restructuring and adding content to instructions	Content, design		4	0.18	0.85	N=1
Keyboard n=3	Hard to enter a value on a keyboard due to its small size	Keyboard, small size	Physical	2	0.09	0.43	N=1
	Lack of understanding of how to use the keyboard	Keyboard, design	Cognitive	1	0.05	0.21	N=1
Prompt n=3	Lack of understanding of the prompt message	Prompt, content		2	0.09	0.29	N=2
	Inability to see and understand the text	Prompt messages, small font size	Visual	1	0.05	0.21	N=1

Table 47 – Usability problems with the app (i.e., themes), their description, and related design features and characteristics *(Continued)*

Themes	**Usability Problem Description**	**Design feature and related characteristic**	**Ability Required to Perfom the Task**	**Number of Times Problem was Reported**	**Mean, M**	**Standard Deviation, SD**	**Number of Participants, N**
Text box n=1	Lack of understanding of how to use the text box	Text box, design	Cognitive	1	0.05	0.21	N=1
Colors n=1	Lack of bright color in Settings	Color, choice	Visual	1	0.05	0.21	N=1

1. Navigation: The main issue with the user interface of the app was navigation. Firstly, sixteen participants commented that they were confused about where to go to enter new data (n=44). The majority of these participants commented about where to find Mood (n=21, N=15). This was not surprising because the task one asked the participants to look for Mood(within Diary feature) and not Diary with the intention to understand the intuitiveness of the Home page, app's functionalities, and the content of Diary, which is the main functional feature of the app. Additionally, they had issue with finding where to enter happy mood (n=1, N=1), find reports (n=1, N=1), find symptoms (n=2, N=2), find Sleep page (n=1, N=1), find Activities page (n=1, N=1), enter difficulty (n=2, N=2), find the MS news (n=5, N=5), measure the blood pressure (n=1, N=1), find the healthcare provider's contact information (n=7, N=4), enter the personal information (n=3, N=3), and change the text size (n=1, N=1).

Secondly, nine participants mentioned the navigation with Next and Back buttons (n=16). For example, P22 commented that Back button has a good function, but Next button is not needed for the navigation:

"I think that not having to push Next and having automatically (a page) to pop-up. Back is fine, but Next."

They expected that after making a selection the following page would open and they would not be required to tap on Next button. However, once they were explained the reason for this way of the navigation, participants understood the benefits of it and appreciated that they could switch from novice to expert users.

Thirdly, three participants mentioned that after a double selection on one page, they were not sure if they needed to open the following page to get the second selection (n=3). Two participants tapped on “Add symptom” button with the intent to add difficulties (n=3).

2. Feature Request: Eight participants suggested new features that would benefit the app (n=27). For example, P6 and P7 suggested to add a drop-down menu with MS types instead of the text box (n=2), and P21 and P22 recommended buttons instead of the text box and drop-down menu because the drop-down is hard to use. P12 suggested having the option to add mood, symptoms, difficulties, activities and heat in Diary multiple times per day (n=5), as well as an important event that can affect the symptoms (n=1). They also suggested to merge Vitals and Goals and have current values and goals within the same feature (n=1) and to add diet to goals (n=1). P22 asked to have both current weight and a goal together (n=1). P12 asked to add a question “Are you on a good therapy medication?” because that can cause new symptoms (n=1) and to have a photo, personal information, and medications in one place, that can substitute the MS card (n=1). P1 asked where the progress can be seen after they set up the goals (n=1). P6 asked about the reminders for measuring blood pressure (n=1). P18 asked if it would be possible to select multiple moods (n=1). P21 asked if there is a way in MS Friends to search for people of a certain demographic (n=1) and if they can speak with a friend that knows another language (n=1) and suggested to share the name of a doctor in personal information (n=1). P22 suggested to have icons instead of the comment section for the side and part of the body for symptoms (n=2), sleep notes (n=1), more adjectives for sleep quality (n=1), and number of times one wakes up during the sleep (n=1).

3. Slider: Next, six participants asked how to use the slider (n=7). P14 asked "Will this make it a 4 if I do this?" when using the time slider this participant wanted to change the value for severity. Additionally, one participant had a suggestion about the improvement of the design of the slider and another one recommended to replace the slider with a check box or a few buttons with the values in it. Two participants commented about the difficulty using the slider (n=2).

4. Button design and page layout: Three participants assumed that "Manual input" button was just a title of the page (n=3). Two participants thought that the top navigation bar icons were clickable (n=3). One participant asked if the goal weight is the current one and suggested to put bold question about the weight goal above the text box (n=1), one did not know how to deselect the button (n=1), and one did not see the gender buttons in personal information (n=1).

5. Other usability problems: Four participants thought that "Emergency contacts" should be renamed and provided suggestions, such as "Health contacts" and "Frequent contacts" (n=7), and one participant suggested that "Excited" should be renamed into "Fabulous."

Three participants suggested improvements to the design of the icons (n=4). For example, P3 thought that Display and Sound icon in Settings has sound as dominant feature. P14 recommended that Profile icon "needs to be a little bigger," and P18 confirmed the size of Profile and Settings icons look too small: "I didn't see that."

One participant gave recommendations for the Instructions (n=4). For example, P19 asked that there is instruction about how to change novice to expert user mode, suggested to have the instructions content "more conversational," write the content in bullet points, and answer the question "Why?" there is a need for the specifics within the instructions.

Another participant commented that the keyboard is too small (n=2) and the other one asked how to erase the input value (n=1). Two participants had problem with understanding the content of the prompt message (n=2), and one could not read it because of the small font size (n=1). Lastly, one participant asked how to write in the text box (n=10), and one commented that Settings should be in a color and not grey because of the use of bright colors throughout the app (n=1).

4.2.3.2.2.1.2 Positive Feedback

In addition to reporting problems with the mobile application, the participants commented about the positive aspects of the functional and design features. For example, P1 stated that:

> *"I think it's fantastic. I would actually use this. Other MS apps are not that good. Every morning I do a "MS report". Even if I don't send it to my doctor, it's useful to me. If something strange happens, someone else can see it and tell a doctor."*

P1 added that they liked alphabetizes items on the pages (n=1), logical structure of the app (n=1), colors (n=1), and consistency (n=1). P1 and P12 liked the size and layout of the buttons (n=2, N=2). P1 and P16 thought that it was easy to navigate using Next and Back buttons (n=2, N=2). P21 liked the use of a single tap throughout the app.

Some participants commented that they liked the size and the colors of the Home page buttons (n=3, N=3), the design of the pages (e.g., MS Friends calling page, Diary page, n=2, N=2), the feedback that the text size slider provides (n=2, N=2), the calories feedback (n=2, N=2), the confirmation that the reports have been sent successfully (n=1), the option to select the personal information to share (n=1), and the conciseness of the app (n=2, N=2).

A few participants commented about a benefit of the Settings features. For example, P11 appreciated the existence of both novice and expert user modes (n=1), P12 praised the presence of the speech input (n=1), P19 liked that there was an option to invert the colors (n=1) and added *"You cannot account for everybody, but still this is really good,"* and P21 commented that it is good to have the notifications (n=1) and settings within an app (n=1):

> *"That's good. It is confusing with other apps when you have to go to Settings and set up the app."*

P12 commented about the functionality of the app:

"What is different about this app is that you can email your current symptom to doctor."

A few participants appreciated having the games on the app (n=3, N=3) and P13 mentioned that "I need to get one of these games." P16 added that they like the functionality of games, goals, and vitals. P1 liked the reports feature (n=1).

4.2.3.2.2.2 SUS Questionnaire – Subjective Satisfaction

SUS questionnaire resulted in the SUS scores within a range of 45 – 97.5. The average SUS score from all the participants is M=76.14, SD=19.19. This score is above average of 68, and it is translated into grade B a percentile rank around 77%.

4.2.3.3 Design Implications

Overall, participants rated all the design features highly with the mean of all the ratings within a range of 4.05 – 4.86. The majority of the features were rated as 4 and 5.

Design criteria DE2b that represents "system feedback for the actions, such as a beep when pressing a key" was rated the lowest because some participants did not hear the sound (N=5) and rated it very low (rating=1, N=2; rating=2, N=1; rating=3, N=2). The second lowest rating was for design criteria IC1a that represents "the same means of use for all users, by eliminating specialized design and language" (M=4.14). Five participants rated is as 3 and the others as 4 and 5. Rating of 3 was given when participants were not sure how to rate the feature. They wanted to have MS displayed on the main icon for the app, which made it distinguishable from the other icons (Figure 25). The difference was found a good aspect since participants wanted a single app for the management of the condition and did not think that it should be hidden.

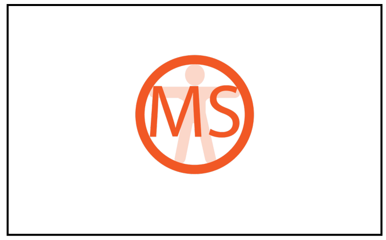


Figure 25 – Main icon of the app

The next lowest mean rating was equal to 4.23 and was given to IC2d: “more than one way to go to different pages while keeping the consistency.” Four participants rated it as 3 because they did not realize that they can navigate through the interface using both random access and linear navigation. Mean rating of 4.27 was given to DE2a “feedback about a confirmation of my activity and a current state” because five participants rated it low due to an initial lack of understanding of the script (rating 2, N=1; rating=3, N=4). Mean rating of 4.32 was given to IC5b “related information in a group, and the most frequent operations highest on the page” because 4 participants who gave the rating of 3 could not recall the layout of the page and were not clear how to rate the feature.

All other design features were rated very highly (M=4.41 and above). The highest mean rating was given to IC7a “understandable reading level of text material” (M=4.86). The next two highest ratings (M=4.82) were given to IC13a “use of a single tap throughout the app instead of double-clicking,” IC10a “configuration of the display settings to my needs and preferences, such as text size, contrast,” and IC5a “clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games).” There is a significant difference between the lowest mean rating (M=4.05) for DE2b and the highest mean rating (M=4.86) for IC7a ($t(21)=3.015$, $p=.007$). This suggests that there is a room for the improvement of the DE2b. However, the sound feedback after pressing a key is a smartphone device system feature, and it cannot be addressed from the design point.

The second lowest mean rating (M=4.14) for IC1a and the highest mean rating (M=4.86) for IC7a were statistically different as well ($t(21)=4.4029$, $p=.0002$). Since all participants wanted to have MS displayed on the main app icon, there is no need for a design change.

The next lowest mean rating (M=4.23) for IC2d and the highest mean rating (M=4.86) for IC7a were statistically different (*t*(21)=3.853, *p*=.0009). This suggests that there is a room for improvement of the IC2d "more than one way to go to different pages while keeping the consistency." This can be done by adding a short tutorial or instruction to explain the two ways of navigation.

The mean rating (M=4.27) for DE2a and the highest mean rating (M=4.86) for IC7a were statistically different (*t*(21)=3.095, *p*=.005). It does not need a redesign because the low ratings were due to the lack of understanding of the script. The feedback of the activity and a current state were obvious by changing the color of the button in addition to the audio feedback.

The difference between mean rating of 4.32 that was given to IC5b and the highest mean rating (M=4.86) for IC7a was statistically significant (*t*(21)=3.206, *p*=.004). Four participants who rated it as 3 could not initially understand how to rate this feature and were not sure what this design criteria refers to. Therefore, there is no implication for redesign of the feature or the mobile app.

4.2.3.3.1 Summary of Potential Design Changes of MS Assistant

Based on the evaluation of the app, I provide a summary of potential design changes of MS Assistant.

1. Navigation: To solve the problem with the confusion about where to enter new data, simple labeling changes should be implemented. For example, participants recommended to rename "Diary" into "Journal" because they take daily health and wellness notes, which they call "journaling." They suggested to rename "Emergency Contacts" into "Frequent Contacts." Participants recommended to redesign Profile and Settings buttons to look bold. Instructions should have information that Difficulties page comes after Symptoms page.

Participants had a problem with understanding the use of "Add …" buttons (e.g., “Add difficulty,” “Add game,” “Add contact”) and mostly tried to use it to open the pages. Since those buttons have a value for the end-users who want to add new symptoms, activities, difficulties, games, and contacts, the buttons should be kept but can be moved to the bottom of the page. Only four participants had issues with understanding of the sequence required to navigate through the app. They expected the page to open after they made a selection (i.e., pressed the button). However, when I explained the benefits of the linear navigation and double selection using Next and Back buttons to them, they understood its importance and thought that it is easy to learn. Issues with the double page selection (i.e., after the double selection on a page, each selected feature has its own page) can be solved by adding “page 1 of n” at the bottom of the page or with page control (i.e., page indicator, a control that displays a horizontal series of dots, and each dot corresponds to a page). Three participants asked for help after the prompt message appeared and they got confused about the navigation. The clarity of the prompt message information can be improved by changing its content.

2. Slider: The second usability problem with the app was the lack of understanding of how to use the slider and difficulty using it. The slider can be replaced with the text box or a set of buttons when there are a few options to choose from.

3. Button Design and Page Layout: The issue with understanding that “Manual Input” button is an actual button can be solved by placing the button at the bottom of the page. Top navigation bar icons looked clickable to three participants. Their role is to represent the page and give information about the users’ location within the interface.

4. Other Errors: Some minor usability problems with the mobile app include the issues with the keyboard. The keyboard should be initially replaced with the larger one and users should have the option to increase its size within the Settings. Three participants had a problem with reading and understanding the information presented in the prompt messages due to the small size of the prompt message and small font size. I followed the UDMIG v.2.1 and the design criteria related to the font size throughout the app and participants did not have problems with the size of the text. However, the size of the prompt message and its text were constrained by the operating system and could not have been increased. One participant did not understand whether the current or the goal weight was required to enter in the goal weight. They suggested to ask “What is your goal weight?” at the top of the text box for the weight goal. Two participants asked for help due to the existence and the layout of the second page in Reports. Page control (i.e., page indicator, a control that displays a horizontal series of dots, and each dot corresponds to a page) or “page 1 of n” at the bottom of the page are recommended to solve this usability problem. One participant suggested that “Excited” should be renamed into “Fabulous,” and another one thought that Display and Sound icon in Settings has sound as dominant feature that should be smaller. One participant gave suggestions about the improvement of Instructions. For example, they asked to add text about how to change novice to expert user mode, suggested to have the content “more conversational,” write it in bullet points, and answer the question “Why?” when listing the specifics within the instructions.

5. Feature Request: Eight participants suggested new features that would benefit the app. For example, two participants suggested to replace the text box for MS types with a drop-down menu. However, the drop-down menu is hard to sue by an aging population and was avoided following the design criteria. Another two participants recommended buttons instead of the text box and drop-down menu because they confirmed that the drop-down is hard to use. One participant suggested reporting helth and wellness data multiple times per day, as well as an important event that can affect the symptoms. They also suggested to merge Vitals and Goals features to have both current and goal values within the same functionality. Another participant focused on the weight and asked to have both current weight and a goal together. One participant asked to add a question “Are you on a good therapy medication?” because it can cause new symptoms. They also suggested to add a photo to Profile feature, so that it can substitute the MS card they are currently using. One participant asked about the reminders for measuring blood pressure. Another participant asked if there is a way in MS Friends to search for people of a certain demographic, to speak with a friend that knows another language, and to share the name of a doctor with MS friends.

4.2.3.4 Discussion

The results of this usability testing confirm the effectiveness of the UDMIG v.2.1 within the application to MS Assistant. The refined application of the guidelines to the design of the mHealth app scored well. Most of the participants favorably agreed that the guidelines were effective in their implementation to the mobile app. The majority of the mean values of the participants' ratings of the design features, which were implemented in the design of MS Assistant based on the guidelines, were equal to 4 or higher. The design guidelines that had the lowest mean ratings (e.g., M_1=4.04, M_2=4.14, M_3=4.27, M_4=4.32) got those ratings because participants did not hear the sound feedback, they acknowledged the existence of MS label on the main icon of the app but wanted to have it displayed on it, or they had problems understanding the script. Only one of those ratings (M=4.23) that is *related to UDMIG* resulted in the recommendation that instruction or tutorial explaining the existence of both the linear navigation and random access should be added to the interface.

Moreover, the evaluation of MS Assistant revealed a small number of minor usability problems with the interface that can be addressed by refining the design of the mHealth app with slight changes. Some of those design changes are based on the participants' recommendations of the improvements related to the minor usability problems in the app. For example, the most frequent problem was confusion over where to go to enter new data, which can be solved simply by renaming the "Dairy" into "Journal" and "Emergency Contacts" into "Frequent Contacts." Additionally, participants proposed to redesign Profile and Settings buttons to look bolder. Instructions should have information that Difficulties page comes after Symptoms page. Home page in MS Assistant was designed based on the design guidelines. Here, mainly the lack of understanding of the meaning and the content of the few main functional features (i.e., Home page buttons) created a problem with the navigation. The only usability problems related to the UDMIG were the design of the buttons for Profile and Settings, which should be made more prominent and bolder. Overall, participants were satisfied with the app, and most of them commented positively about it.

Identified usability problems can be grouped into three categories: the problems *non-related to the UDMIG*, *implementation issues*, and the ones *related to the UDMIG*. Usability problems *non-related to the UDMIG* were the issues with navigation due to confusion about where to enter new data because of the wrong labeling (i.e., use of terminology). Functional features should be named to meet the expectations of end-users and to be familiar and recognizable to the target population. The user needs studies should be used to explain and identify the use of correct terminology. Another usability problem with the app was the lack of understanding of how to use the slider and difficulty using it. The slider was chosen because of its use throughout the app for changing the values that have greater ranges (e.g., time when a symptom started and ended, which represents the duration of the symptom; a time when a person went to bed and woke up, which shows the total sleep time). It can be either redesigned to be easier to use or replaced with the text boxes or a set of buttons in a case when there are a few options to choose from. In the case of the slider, I followed the design guidelines, but a better choice of the design element could be used to improve the design of the app and to better depict the use of the UDMIG.

Navigation issue due to confusion about the meaning of "Add …" buttons (e.g., "Add difficulty," "Add game," "Add contact") was an *implementation issue,* which happened due to the poor choice of the page layout. This usability problem can be solved by moving those buttons to the bottom of the page, and further complying to the IS5b (i.e., related information in a group and the most frequent operation highest on the menu structure) and IS14c (i.e., the location of the buttons near the center or the bottom of the screen), and by adding the explanation about it to the instruction page. The "Add …" buttons have a significant value for the end-users who want to add new symptoms, activities, difficulties, games, and contacts. Other *implementation issues* were the problems with the button design and page layout because "Manual Input" button looked like a title, a problem with reading and understanding the information in the prompt messages due to the small font size, an issue with navigation due to confusion about where to enter new data because of the design of Profile and Settings buttons, a problem with the double selection (i.e., after a double selection on a page, each selected feature has its page) that can be solved by adding a page control (i.e., page indicator), and a problem with understanding of the navigation after the prompt message appeared.

Usability problem *related to the UDMIG* that was not effective was the lack of understanding of the sequence required to navigate through the app due to the linear navigation using Next and Back buttons. However, in the case of a mHealth app for people aging with disabilities, linear navigation has evident importance and the app design will follow the guidelines by implementing two ways of navigation (i.e., random access and linear navigation).

4.3 Effectiveness of the Functional Features in MS Assistant

To answer Research Question 5, I asked participants of the usability testing to rate the usefulness and importance of the functional features in MS Assistant. I collected user outcome measures, such as *the ratings of usefulness and importance* of the functional features in the app.

4.3.1 Methods

Usability testing of the mHealth app with individuals aging with MS was also conducted to assess the utility of the mHealth app by rating usefulness and importance of its functional features. At the end of the previously described usability testing (Section 4.2.3), I asked 22 participants to rate the usefulness and importance of the functional features in MS Assistant after they have performed all the tasks on the mHealth application. Participants' demographics, testing devices, and study procedures were previously described in section 4.2.3.1 (Methods). Following the tasks completion and the usability questionnaires, the participants rated the utility and importance of fifteen functional features in MS Assistant (Table 48) on a 5-point scale (from 1- not useful at all to 5 – very useful, and from 1- not important at all to 5 – very important, respectively).

Table 48 – The list of functional features rated by the participants during the usability testing

Functional Features (and) Their Descriptions
Diary - Health and wellness self-reporting
Reports - Creating and sharing the reports
MS Friends - Community forum, social support
Games - Games and VR that improve cognitive functioning and balance
Resources - MS education, news, research, health and wellness tips
Goals - Plan or orders
Vitals - Health and wellness tracking using wearables, such as Fitbit
Vitals – Telehealth
Emergency Contacts
Reminders and alerts
Gamification - Achievements
Profile - Medication adherence
Profile - Personalization
Settings - Customization
One app that integrates all needed features

Vitals was divided into two categories (i.e., telehealth and tracking of health and wellness using wearable devices) because I wanted to investigate whether there was a difference in how participants perceived the usefulness and importance of the two groups.

Profile feature was split into two sections (i.e., personalization, which is the main features in Profile, and medication adherence) to ask separately about the importance and usefulness of the medications intake tracking.

4.3.1.1 Outcome Measures

The 5-point Likert scale (from 1- not useful at all to 5 – very useful, and from 1- not important at all to 5 – very important, respectively) was used to report *the usefulness and importance ratings* of the functional features.

4.3.2 Results

Participants rated the *usefulness* of the functional features highly and within a range of mean ratings of 4.27 - 4.82 (Table 49). The feature with the lowest mean rating was MS Friends (i.e., social support and community forum), and the one with the highest mean rating was Settings (i.e., customization within the app).

The difference between the lowest mean rating (M=4.27) for MS Friends and the highest mean rating (M=4.82) for Settings was found statistically significant ($t(21)=3.225$, $p=.004$). Games and Resources got the second lowest mean ratings (M=4.41). The difference between the mean rating of each of these two features and the highest mean rating (M=4.82) for was statistically significant ($t(21)=2.857$, $p=.009$; $t(21)=1.901$, $p=.071$, respectively). The mean ratings per participant were within a range of 3.73 – 5. There were three participants whose average of ratings was lower than 4. In addition to the participant with the lowest ratings (M=3.73) who rated communication feature and having a holistic app as 2, two other participants did not give a higher rating than 4 to any of the functional features ($M_1=3.80$, $M_2=3.93$).

Table 49 – Usefulness ratings of the functional features in MS Assistant

Functional Features (and) Their Descriptions	**Ratings, Mean, M**	**Ratings, Standard Deviation, SD**
Diary - Health and wellness self-reporting	4.73	0.55
Reports - Creating and sharing the reports	4.64	0.58
MS Friends - Community forum, social support	4.27	0.88
Games - Games and VR that improve cognitive functioning and balance	4.41	0.67
Resources - MS education, news, research, health and wellness tips	4.41	1.01
Goals - Plan or orders	4.45	0.74
Vitals - Health and wellness tracking using wearables, such as Fitbit	4.68	0.57
Vitals – Telehealth	4.68	0.48
Emergency Contacts	4.73	0.55
Reminders and alerts	4.55	0.67
Gamification - Achievements	4.64	0.58
Profile - Medication adherence	4.45	0.67
Profile - Personalization	4.55	0.51
Settings - Customization	4.82	0.39
One app that integrates all needed features	4.64	0.73

The *importance* of the functional features was rated highly, and those ratings were within a range of 4.09 - 4.73 (Table 50). The least important feature was Games (i.e., classic and VR games that improve cognitive functioning and balance), and the most important one was Settings (i.e., customization within the app).

The difference between the lowest mean rating (M=4.09) for Games and the highest mean rating (M=4.73) for Settings was statistically significant ($t(21)=3.048$, $p=.006$). Personalization within Profile feature got the second lowest mean ratings (M=4.23). The difference between the mean rating of this feature and the highest mean rating (M=4.73) for Settings was found statistically significant ($t(21)=2.746$, $p=.012$).

Table 50 – Importance ratings of the functional features in MS Assistant

Functional Features (and) Their Descriptions	Ratings, Mean, M	Ratings, Standard Deviation, SD
Diary - Health and wellness self-reporting	4.55	0.67
Reports - Creating and sharing the reports	4.59	0.73
MS Friends - Community forum, social support	4.27	0.83
Games - Games and VR that improve cognitive functioning and balance	4.09	0.92
Resources - MS education, news, research, health and wellness tips	4.45	0.86
Goals - Plan or orders	4.45	0.67
Vitals - Health and wellness tracking using wearables, such as Fitbit	4.55	0.67
Vitals – Telehealth	4.59	0.50
Emergency Contacts	4.64	0.58
Reminders and alerts	4.55	0.74
Gamification - Achievements	4.36	1.00
Profile - Medication adherence	4.45	0.67
Profile - Personalization	4.23	0.87
Settings - Customization	4.73	0.55
One app that integrates all needed features	4.68	0.65

The mean importance ratings of functional features per participant were within a range of 3.47 – 5. The same three participants had the average of importance ratings lower than 4 in addition to one more user. The participant with the lowest ratings (M=3.47) Participant with the lowest mean rating of 3.47 rated games, resources, reminders and alerts, and gamification as 2. The participant who rated the usefulness with lowest scores had a higher mean rating of importance of M=3.87. The same two participants as with usefulness ratings did not rate the importance of any feature higher than 4 (M_1=3.67, M_2=3.87).

4.3.3 Design Implications

Participants rated the usefulness of the functional features highly and within a mean rating range of 4.27 - 4.82. The least useful feature was MS Friends (i.e., social support and community forum), and the most useful one was Settings (i.e., customization within the app). The next useful features were health and wellness self-reporting (i.e., Diary) and Emergency Contacts (M=4.73). These findings confirm the usefulness of the main functionalities, which is a self-monitoring of health and wellness and emergency response. Participants rated Vitals functional feature, which was divided into the health and wellness tracking using wearables, such as Fitbit, as well as telehealth as the next useful functionality (M=4.68). Therefore, participants found that all the main functional features that represents the purpose of the app, which is self-monitoring of the health and wellness that includes self-reporting and tracking of data, are its most useful functionalities.

The difference between the lowest mean rating (M=4.27) for MS Friends and the highest mean rating (M=4.82) for Settings was statistically significant ($t(21)=3.225$, $p=.004$). Games and Resources got the second lowest mean ratings (M=4.41). The difference between the mean rating of each of these two features and the highest mean rating (M=4.82) for Settings was found statistically significant ($t(21)=2.857$, $p=.009$; $t(21)=1.901$, $p=.071$, respectively). Therefore, the functionalities that represent communication, use of games to improve cognition and balance, and MS-related resources, such as news, research, health tips, were not found as useful as the integration of the settings within an app.

Similarly, the importance of the functional features was rated highly, and those mean ratings were within a range of 4.09 - 4.73. The least important feature was found to be Games (i.e., classic and VR games that improve cognitive functioning and balance), and the most important one was Settings (i.e., customization within the app). The second most important functional feature was having one app that integrates all other features and serves as a comprehensive tool for the management of the condition (M=4.68). The next important feature was Emergency Contacts (M=4.64). Participants recognized the need for an immediate response in a case of an emergency.

The difference between the lowest mean rating (M=4.09) for Games and the highest mean rating (M=4.73) for Settings was statistically significant ($t(21)=3.048$, $p=.006$). Personalization within Profile feature got the second lowest mean ratings (M=4.23). The difference between the mean rating of this feature and the highest mean rating (M=4.73) for Settings was found statistically significant ($t(21)=2.746$, $p=.012$). Therefore, the functionalities that represent games that improve cognition and balance and personalization of the app were not found as important as the incorporation of the settings feature within an app.

4.3.4 Discussion

The results of the utility questionnaire confirm the effectiveness of the functional features in MS Assistant, which were designed based on the recommendations of the needs assessment study with people aging with MS. Individuals aging with MS found all the implemented functional features highly useful and important. The usefulness and importance of all the features were rated above 4.

Overall, the utility of all functional features was rated highly, and customization of the settings features within an app was found to be the most useful and important. Participants rated self-monitoring of health and wellness (i.e., Diary) and Emergency Contacts as the second most important features in the app following Settings. This is an important finding that confirms the utility of the app and its main functionality to self-report and track users' health and wellness data and provide emergency response.

Moreover, participants rated having one comprehensive app that integrates all other features for the condition self-management as the second most important functionality following Settings feature. These results confirm the formative study finding that individuals aging with MS need a holistic app that presents a complete health and wellness system for the management of MS. A single self-management app would help them understand and learn about their condition by recognizing and managing all the factors that possibly contribute to symptoms and exacerbations, and by keeping the records of all the patterns and trigger factors.

4.4 Summary

I designed and developed the self-management mHealth application, MS Assistant, to validate the UDMIG. Two iterative evaluations of the app were conducted to test the effectiveness of the design features with the purpose to validate the guidelines. These studies reported that the UDMIG applied to the design of MS Assistant meet the usability requirements of individuals aging with MS. Moreover, the utility evaluation of MS Assistant with the end-user population was conducted. It confirmed that the mobile app and its functional features meet their health and wellness self-management needs.

CHAPTER 5. VALIDATION OF THE UDMIG V.2.1

The purpose of this research project was to develop and validate the UDMIG to assist with the design of the future mobile user interfaces for an aging population, including the users with disabilities. Analysis of the current design strategies, two formative studies, refinement of the guidelines, the design of the mHealth app, and two summative studies, which were a part of an iterative evaluation, were conducted to validate the latest version of the guidelines, the UDMIG v.2.1.

5.1 Development of the UDMIG

Four most commonly used design strategies to guide the design of mobile interfaces for an aging population were analyzed in this research study. Individually, none of the four design strategies that were analyzed for the purpose of this study were found to be sufficiently comprehensive or inclusive within a context of mobile interfaces for the aging population. However, taken together, the four strategies provide a complete platform for a more inclusive set of guidelines. The process and outcome of incorporating the three strategies into UD, and a resulting comprehensive set of design guidelines for interactive mobile interfaces for the aging population are detailed in later in this chapter.

I developed UDMIG v.2.0 to ensure the usability of future mHealth applications by older adults through a universal design strategy that accommodates all users to the greatest extent possible. Nonetheless, while the guidelines are intended to promote universal usability, they require validation through the application and evaluation with users who represent a range of abilities. MS Assistant was developed and tested as an MS-specific mHealth application for the purpose of the validation of the UDMIG.

5.2 Refinement of the UDMIG Through the Development of the mHealth Application for People Aging with MS

5.2.1 The Needs Assessment Study: Health and Wellness Self-Management Needs of People Aging with MS and Related Functional Features in Mobile Applications

The goal of this qualitative study was to identify the specific needs for self-managing health and wellness among the individuals aging with MS and to find the opportunities to meet those needs through the development of future MS-specific mobile applications. I found out that individuals with MS write physical notes detailing the health and wellness information (e.g., mood, current weather, sleep length and quality, activity level, symptoms, remissions, and similar) on a daily basis and take those logs to the neurologists during every visit. These notes help them be aware of themselves and their condition. More importantly, the logs help them understand what affects and causes their symptoms and exacerbations. The participants suggested that mobile technologies could be used instead of note-taking to help them with this type of health self-management. This critical finding opens the door for innovation in the field of mobile technologies related to ways of tracking and self-reporting health and wellness data in people with MS. People with MS need to track and report wellness data, such as mood, activity, sleep, and others, similar to people with other chronic condition. However, what distinguishes individuals with MS from others with a chronic condition is the importance of monitoring their symptoms, relapses, and remissions together with other wellness, weather, and geolocation data to understand how these side factors affect their immediate health. They want to know what affects their symptoms and causes exacerbations to possibly prevent or decrease their occurrence, intensity, and distress.

In this study, participants discussed a number of needs for the health self-management including health and wellness self-reporting and tracking, creating and sharing reports, including medical records and medication adherence, availability of MS news, research, tips, and resources, reminder and alarm systems, social support of people with MS, telehealth (health tracking), and virtual experiences. During the focus group conversations, they talked about the potential support for these needs through mobile technologies and specific functional features. Each of the identified needs resulted in a feature, such as a journal, reports, MS education, reminder and alerts, MS community forum, telehealth, and VR. Additionally, discussion about the VR games expanded that functionality into VR and games, which would include games that improve cognition and balance. MS-specific exercises and personalization emerged as additional functional features that were not mentioned as specific health needs.

Individuals aging with MS discussed a need for the holistic app that represents a complete health and wellness system and a way to self-manage MS. A comprehensive self-management app would help them understand their condition by recognizing and managing all the factors that possibly contribute to their symptoms and exacerbations, and by keeping records of all the changes and what causes them to identify trigger factors and patterns. Participants aging with MS expressed the need for an integrative app, which helps them log and track health and wellness data, keeps the MS data in one place, including medical reports and medications, sends the report with all this information electronically to help them with data accuracy and timesaving, provides reminders and alerts to assist with medication adherence, daily tasks, and emergencies, communicates with other individuals with MS to get the social support, has all the relevant MS resources, news, and research, connects with wireless health devices to ease the health management, and provides the games that improve their cognition and balance within a personalized and customizable system. Moreover, the stored data should be available to their healthcare providers, family members, and caregivers to alert them in a case of an emergency or a special need. However, they had a concern about data security and privacy related to having cloud-based and online medical reports.

5.2.2 *Usability of mHealth Applications for Individuals Aging with MS*

I evaluated the usability of two current MS health and wellness self-management mobile applications and one health app for the general population to identify the effectiveness of app attributes and provide recommendations for the design of new mobile user interfaces for the target population. The study resulted in a set of evidence-based design recommendations to assist with the future development of mHealth user interfaces for older adults, including people aging with disabilities. The most important design elements that need to be considered when developing mobile applications for population of people aging with MS are: navigation, locating the Home page and other pages within the interface, task completion, instructions, appropriate size of the fonts, buttons, and icons, high color contrast, and avoiding the use of scrolling and the picker represent. The recommendations characterize the most important design elements that need to be considered when designing and developing mobile apps for an aging population.

5.2.3 *Refinement of the UDMIG to Include People Aging with Disabilities*

The initial version of the UDMIG was designed for an aging population. Two formative studies (i.e., needs assessment study using focus groups and usability testing of the current mHealth apps with older adults and people aging with MS) provided the design and utility recommendations for the development of mobile applications for people aging with MS and informed the UDMIG to include individuals aging with disabilities. Based on each UDMIG v.2.1 guideline, corresponding design criteria were created to guide the design of MS Assistant.

5.3 Design and Testing of MS Assistant to Validate the UDMIG

5.3.1 Design of MS Assistant

I designed MS Assistant based on the results of the two formative studies as a holistic and personalized app (i.e., needs assessment study and usability testing of the current mHealth apps). It provides the functionalities identified in the formative needs assessment study. Additionally, I designed the user interface of MS Assistant based on the UDMIG v.2.1 design criteria to provide universal usability with simple and clear interaction and navigation.

5.3.2 Effectiveness of the Design Features in MS Assistant: Iterative Evaluation

I conducted an iterative assessment of the UDMIG v.2.1 through its application to the mHealth app design with the purpose to validate the design guidelines. First, I conducted an expert review, which was used to evaluate the effectiveness of UDMIG v.2.1 in the design of MS Assistant. The results suggested that the expert evaluators rated well the implementation of the guidelines and its design characteristics to the design of the mHealth app. In addition, they identified a small number of design elements that needed minor improvements and recommended possible refinements. I then redesigned MS Assistant based on these recommendations. Lastly, I conducted usability testing of MS Assistant with individuals aging with MS to assess the overall usability of the mHealth app to determine the effectiveness of UDMIG v.2.1 in producing a universally usable product. This was a second assessment of the guidelines as a part of the iterative evaluation process following the expert review.

5.3.2.1 Expert review

The results of the expert review confirmed the effectiveness of the UDMIG v.2.1 within the application to MS Assistant. Overall, this implementation of the guidelines to the design of the mobile app scored well. Most of the participants favorably agreed that the guidelines were effective. Ninety percent of the mean values of the participants' ratings were equal to 4 or higher. In addition, there was a small number of recommendations related to the minor usability problems in MS Assistant. Design changes addressed the usability-related suggestions made by the expert reviewers.

5.3.2.2 Usability testing with People Aging with MS

The results of this usability testing confirm the effectiveness of the UDMIG v.2.1 within the application to MS Assistant. The refined application of the guidelines to the design of the mHealth app scored well. Most of the participants favorably agreed that the guidelines were effective in their implementation to the mobile app. The majority of the mean values of the participants' ratings were equal to 4 or higher. In addition, participants recommended a small number of improvements related to the minor usability problems in MS Assistant.

Moreover, the evaluation of MS Assistant revealed a small number of usability problems. Usability issues identified when participants requested help corresponded to the problems with the user interface identified by counting the errors they made while performing the tasks. The problems with the selection that were identified by counting errors revealed additional minor usability issues. The most important usability problem found was the issue with navigation and the confusion over where to go to enter new data.

5.4 Validation of the UDMIG v.2.1

To prove the main thesis statement and to address specific aim 3, the UDMIG v.2.1 were validated through an iterative assessment of the guidelines and its application to the design of MS Assistant. I conducted two evaluations: expert review and usability testing with the end-users, to evaluate the effectiveness of the design features in MS Assistant and to validate the UDMIG v.2.1. Both studies were designed as mixed-methods studies that reported quantitative and qualitative data. Specifically, I tested the effectiveness of the design features, the effectiveness of the app, and satisfaction with the mHealth app.

Based on the results of the two research studies, the application of the UDMIG v.2.1 to MS Assistant was effective, and the design guidelines were validated. These studies reported that the UDMIG applied to the design of MS Assistant meet the usability requirements of individuals aging with MS.

Usability problems related to *implementation* and problems *related to the UDMIG* that were not effective validated the UDMIG. For example, usability problem related to *implementation* was the issue with the lack of understanding of the button design and page layout represented in an example of “Manual Input” button. To eight participants, this button looked like a title of the page and not an actual button. This usability problem can be solved by making a better design decision and placing the button at the bottom of the page, which would comply to the design criteria IC14c (i.e., the location of the buttons near the center or the bottom of the screen). Therefore, by complying with the UDMIG more, the design of the app would be improved and more usable, which would further validate the design guidelines. Another example of the poor implementation is the problem with reading and understanding the information in the prompt messages due to the small font size. I followed closely the UDMIG IS6a that states that large enough and legible fonts should be used within the interface (i.e., whenever possible use 14-point and bigger serif or sans serif fonts and use at least 12-point when not). However, due to the limitations with the small size of the prompt message, which is limited by the system, the font size on the prompts was too small and participants found that to be a problem. These system limitations further validate the UDMIG since there were no usability problems within the app, designed based on the UDMIG, related to the font size. Navigation issue due to confusion about the meaning of “Add …” buttons (e.g., “Add difficulty,” “Add game,” “Add contact”) was another implementation issue. This usability problem should be simply solved by moving those buttons to the bottom right of the page to further comply to the

IS5b (i.e., related information in a group and the most frequent operation highest on the menu structure) and IS14c (i.e., the location of the buttons near the center or the bottom of the screen), and by adding the explanation about it to the instruction page. The "Add …" buttons have a significant value for the end-users who want to add new symptoms, activities, difficulties, games, and contacts. Additional example was an issue with navigation due to confusion about where to enter new data because of the design of Profile and Settings buttons that need to be bolder, more prominent, and to look more like buttons. These buttons were partially designed based on the UDMIG. However, there was a limitation of the button size on the top navigation bar. Therefore, the DE1a guideline (i.e., large enough button size) and its related design criteria (i.e., size of the buttons is at least 16.5mm diagonally and 11.7mm square) could not have been followed. This further validates the guidelines since it pinpoints on the problem that was not addressed due to the system limitations. Issues with the double selection (i.e., after a double selection on a page, each selected feature has its page) can be easily solved by adding a page control (i.e., page indicator), which is a control that displays a horizontal series of dots, and each dot corresponds to a page, or “page 1 of n” at the bottom of the page. The app was designed based on the guidelines to keep the consistency related to the navigation and the page layout. In this case, a simple page redesign can improve the problems with the interface. Three participants experienced problems with understanding of the navigation after the prompt message appeared. The clarity of the prompt message information can be improved by changing its content. Non-technical and understanding level of text material was used throughout the app. However, the clarity of those two prompt messages should be improved.

One of the minor usability problems with the mobile app was the issue with the small keyboard. I used the default iOS keyboard, which should be replaced with the large one and the users should additionally have the option to increase its size within the Settings. One participant recommended some improvements to the instructions content. For example, they suggested to add text about how to change novice to expert user mode, proposed to have the content "more conversational," write it in bullet points, and answer the question "Why?" when listing the specifics within the instructions.

Example of the usability problem *related to the UDMIG* that was not effective was an issue with navigation due to the lack of understanding of the sequence required to navigate through the app. Four participants expected the page to open after they made a selection (i.e., pressed the button). This can be easily solved by adding the content about it to the instruction page. The use of both linear navigation with a double selection and random access was implemented based on the UDMIG. Those four participants understood the importance of having two ways of navigation that benefit an aging population and thought that it was easy to learn. Moreover, any user can switch from a novice to an expert user mode if they prefer a fast pace of interaction. Additionally, top navigation bar icons looked clickable to three participants. The role of these icons with the text description is to represent the page and give information about the users' location within the interface. The icons with the text, their top central location, and the color that matches the page color scheme were designed based on the UDMIG. Therefore, the problem may lay in the design and the layout of the page and the clarity of information it provides. The existence of the second page in Reports was not clear to two participants. The page was designed to follow the consistency in the design and navigation. A minor redesign, such as page control (i.e., page indicator, a control that displays a horizontal series of dots, and each dot corresponds to a page) or "page 1 of n" at the bottom of the page can solve this usability problem.

Furthermore, usability problems that were *non-related to the UDMIG* need to be added to the guidelines to address these additional issues identified by the end-users. For example, issue with navigation because of the confusion about where to enter new data due to labeling can be easily solved by paying the close attention to naming functional features based on the expectations of users. User needs studies can be used to focus on the use of the correct and familiar terminology in addition to the health and wellness needs for condition self-management. This issue and proposed solution should be added as a design criterion to the design guideline “IS6. Maximized "legibility" of essential information” to augment the UDMIG. Another example of issued non-related to UDMIG was a lack of understanding and difficulty using the slider, which can be solved by replacing the slider with another design element or (descriptive) buttons when there are a few options to choose from. It can be added to the design guideline “IS4. Simple and natural use” to further strengthen and enhance the guidelines.

Moreover, participants recommended a small number of improvements related to the minor usability problems in MS Assistant. Eight participants had feature requests and suggested new ones that would benefit the app. For example, two participants suggested replacing the text box for MS types with a drop-down menu. However, the drop-down menu is hard to sue by an aging population and was avoided following the design criteria. Another two participants recommended buttons instead of the text box and drop-down menu because they confirmed that the drop-down is hard to use. These findings validate the UDMIG v.2.1. Overall, participants were satisfied with the app and many positively commented about it.

5.5 Summary

To evaluate the guidelines, the researchers (Devezas, Mashapa, Giesteira, Greunen, & Carreira, 2014; Teng, 2015; Van Biljon & Renaud, 2016) implemented the designs strategy and (iteratively) evaluated the application with the end-user population. The guidelines were used to design and develop a mobile app, and the resulting prototype application was evaluated with the end-users.

This research project developed and validated the universal design mobile interface design strategy to help with the design of mobile user interfaces for an aging population, including the users aging with disabilities. A systematic review of the current design strategies, two formative studies, refinement of the UDMIG, the design of the mHealth app, and an iterative assessment of the app were conducted to validate the UDMIG v.2.1.

CHAPTER 6. DISCUSSION

I conducted this research project to develop and validate the Universal Design Mobile Interface Guidelines through its application to the design and development of the mHealth app. Additionally, through this project, I identified the health and wellness needs of individuals aging with MS and functional features in mobile applications that meet those needs to develop the functionality of the mHealth app. Chosen methods began with the studies to explore the current design strategies used for an aging population, to identify the utility and usability needs of end-users in the design of mobile applications, and to iteratively assess the UDMIG and the effectiveness of the design and functional features of mHelath application, designed based on the UDMIG and the user needs study, in meeting the usability and utility needs of the people aging with MS.

6.1 Key Findings and Takeaways with Strengths and Limitations of the Research Methods

6.1.1 Analysis of the Design Strategies to Develop the UDMIG

For the purpose of this study and to address specific aim 1, I analyzed four most commonly used design strategies to address the design of mobile interfaces for an aging population. The result of this integration of the four design strategies was the UDMIG v.2.0, which addressed the usability of the mobile applications for older adults who were characterized by a great number and variety of functional abilities and limitations. However, this version of the design guidelines was not tested to understand whether they include the population of users aging with disabilities. Therefore, I needed to design and develop a mHealth application for individuals aging with disabilities to apply and test the UDMIG. Additionally, UDMIG focused on the usability of mobile applications without taking into an account their utility. To understand the functionality of the mHealth app, I needed to identify the users' health and wellness needs and functional features in mobile apps that meet those needs (Specific Aim 2, RQ 2).

6.1.1.1 Strengths and Limitations

One limitation of this study was that there was a number of other strategies and design guidelines that I could have used in addition to these four major ones. Moreover, I used P-E Fit Model as an organizing principle whereas I could have applied other categorization methods. For the purpose of the systematic classification of the guidelines for this study, P-E Fit Model was an appropriate method that evaluates the match between a user's ability and the requirements of the environment to promote healthy aging.

Moreover, the UDMIG addressed the usability of mobile applications. However, we need to understand the utility of the mobile apps and user needs to design the functionality of the app that meets those needs. User needs assessment studies are required to supplement the UDMIG when designing mobile applications for an aging population and those aging with disabilities.

6.1.2 User Needs Study

6.1.2.1 A Systematic Review of the Functional Features in MS-Specific Mobile Applications

As a background review for the user needs study, I conducted a systematic analysis of the functional features in current mobile apps for people with MS. Half of the apps for individuals with MS focused on the health and wellness self-reporting, creating patterns and charts out of those data and having the option to email that information to the healthcare providers, caregivers, family members and others. One-third of them tracked injection and medication adherence. Two of them were educational apps, and one was a social app for individuals with MS. A few of these mobile apps had more than one functional feature. Consumer MS-specific mHealth applications were limited in their functionality as they offered similar features across the apps and a small number of features within an app. Moreover, none of the apps for people with MS presented the holistic and integrative app that provided their users with a variety of the features including the community forum, telehealth, gamification, and goals, next to the health and wellness self-reporting and tracking of data, creating and sharing reports, and MS education. All apps failed to offer a complete comprehensive health and wellness picture based on its input data and a way to self-manage MS. These apps failed to deliver a comprehensive self-management tool for end-users' to understand their own MS by monitoring all the factors that possibly contribute to the symptoms and keeping track of the changes and what causes them to identify trigger factors and patterns, and by having all that data available to their healthcare providers with the alerts to them in a case of emergency or a particular need.

6.1.2.1.1 Strengths and Limitations

One possible limitation of this study was that there might have been some MS-specific apps that were not identified using the app search.

6.1.2.2 The Needs Assessment Study: Health and Wellness Self-Management Needs of People Aging with MS and Related Functional Features in Mobile Applications

The participants identified health and wellness needs and valuable functional features they need within the integrative mHealth app that are present in current mobile applications for people with MS, such as health and wellness self-reporting and tracking, creating and sharing the health information (including medical records and medications), education about MS (including news, research, resources, and tips), reminders and alert systems. Moreover, they identified functional features that are not present in MS-specific mobile apps. For example, they discussed sending alerts to the healthcare providers, caregivers, and family members in a case of an emergency, which is a unique and critical feature that is not present in any of the apps on the market. Social support was not provided within any of the current apps, except as the main functionality of MS Buddy, a stand-alone app that focuses on the communication among others with the condition. Another significant finding unique to individuals with MS that could be applied to others with motor impairments was that half of the participants wanted to play VR games that would assist them with performing and participating in the physical activities, which they cannot accomplish in the real world. VR has a great opportunity to help people with MS feel active and same as other people by playing the variety of games that mimic certain activities, such as biking, and skiing. The other half did not want to use this technology, which may be due to a lack of familiarity with it. Additionally, individuals aging with MS found that remote monitoring of their vitals (e.g., blood pressure, pulse, oxygen) and wellness, such as activity (e.g., number of steps, miles, and floors) and sleep (e.g., sleep quality and length), can help them better manage MS in a convenient and time-saving way. The field of VR and telehealth present critical opportunities to meet important needs of people with MS. VR is already exploring possible activities and applications that benefit individuals with disabilities and an aging population (Adamovich et al., 2005; Baram & Miller, 2006; Broeren et al., 2004; Charvet et al., 2016; Crosbie et al., 2006; De Giglio et al., 2016; Donoghue & Stokes, 2009; Dvorkin et al., 2006; Esculier et al., 2012; Fung et al., 2004; Lange et al., 2010; G.-H. Lee, 2016; Merians et al., 2002; Merians et al., 2009; Ortiz-Gutiérrez et al., 2013; Rivaetal, 1998; Sanchez et al., 2006; J. C. Stewart et al., 2007; Yuen et al., 2011). Telehealth has gone through a breakthrough moment, and it continues to advance the technology use and to seek new applications (Glueckauf & Noël, 2011).

I found no difference in reported health and wellness needs and functional features between the participants based on their frequency use of mobile apps and functional limitations. However, there was a difference between the responses among the two groups related to the security and privacy of health data and VR gaming. I assumed that this discrepancy happened because of the group interactions and dynamics. The difference in responses about VR might have occurred because of the fact that in the first focus group one of the participants came up with this topic after having an experience with it and the other participants understood it better after the exposure to this elaborate description by one of the group members.

Participants did not discuss goal setting (gamification) as a possible feature. Researchers have reported that goal setting of specific difficult tasks leads to a behavior change and higher performance compared with a lack of or vague goals (Strecher et al., 1995). Additionally, they did not talk about the availability of emergency contacts within this type of app.

6.1.2.2.1 Strengths and Limitations

I presented the participants with three apps, which I found a most representative of the health and MS-specific apps on the market. However, I had a limited time for participants to explore the three apps and comprehend all their functionalities. Longer exposure to these apps would benefit the study as three participants who never used MS-specific apps would get a better understanding of their capabilities.

The drawback of the study was the relatively small number of groups (i.e., two focus groups). However, in a case of studies with individuals with disabilities, researchers have argued that even a small number of participants can help generate plenty of rich qualitative data. The study participants had different impairments and ranges of limitations, which infers that the results of the study can be generalized. Moreover, the researchers recommended smaller group sizes if the purpose of the focus group study is to gain an in-depth understanding of people’s experiences (Krueger, 2014). Smaller groups are preferable when the participants have a lot of information to share about the topic or have had important or lengthy experiences with the subject of discussion. This user needs study delivered a valuable set of data about the functional features that meet the health and wellness needs of people aging with MS, which can be used when designing mobile health and wellness applications. However, because of the relatively small total number of participants (i.e., eight individuals aging with MS), and a limited ability to draw strong general conclusions, a follow-up study to test the usefulness of the identified functional features with the end-user population is needed. First, a mHealth app, MS Assistant, was designed to incorporate all the features identified in this study. Second, I tested its usefulness with individuals aging with MS to understand whether this app and its functionalities met the needs for health and wellness self-management of its target population.

This case study focused solely on the health and wellness self-management needs among individuals aging with MS related to the mobile technologies. However, the findings of this study could be generalized and applied to the design of mHealth apps for other chronic conditions if the appropriate minor adaptations are conducted to account for the differences between MS and the chosen condition. I found that health and wellness tracking and self-reporting were core features of the mHealth apps. Participants wanted personalized information and insights about their condition and self-management. Additionally, they wanted to share this information with specific people, especially with their healthcare professionals for the purpose of time-saving and efficiency. Education, reminders, and community forum were found incredibly useful to our participants and supported by the previous studies for other conditions (Mendiola et al., 2015). In our study, I found that telehealth, VR games, and condition-specific exercises present potential valuable features in health apps. Although participants in this study did not discuss popular and studied functional features, such as goals and gamification (i.e., achievements), those two functionalities were proven to be valuable to end-users (Mendiola et al., 2015).

6.1.3 Formative Study to Refine the UDMIG

6.1.3.1 <u>Usability of mHealth Applications for Individuals Aging with MS</u>

I assessed the usability of the current mHealth apps to understand the effectiveness of the design features and to identify the barriers and facilitators to usability for an aging population and people aging with MS. The results of the usability study implied that older adults performed worse than individuals aging with MS did. Although only three older adults self-reported to have one functional limitation each, and people with MS self-reported total of twenty-seven functional limitations, the frequency of help requests in seniors was almost twice as large as the one in people aging with MS. This might have been due to the differences in tech-savviness, although the self-reported computer and touchscreen experience were not significantly different (t_1 (10) = 1.619, p_1 = 0.137; t_2 (17) = 1.336, p_2 = 0.199, respectively). Another important finding of the usability study was that the categories of the identified usability problems (i.e., themes) were the same across two groups of participants, except for the contrast that was not identified by the group of older adults. Therefore, both user groups encountered the same or similar usability problems with the three mHealth apps. Additionally, the main usability problems were the issues with the navigation and finding certain pages for both groups of participants. Therefore, the main recommendation of this research study was to make mobile applications more usable by simplifying its design and navigation and considering this a vital factor for the design and development of mobile apps for older adults and people aging with MS.

Participants rated fourteen design elements in three tested mobile apps. *MS self* had the highest ratings in both user groups, and seniors rated all three apps lower than the individuals with MS did. However, the differences in mean ratings between two groups of participants were not significant, except in a case of ease of use of touch buttons, swipe, scroll for all three apps, for ease of skipping the content for *iHealth*, which people with MS rated significantly higher than older adults did (t (17) = 2.767, p = 0.014; t (17) = 2.694, p = 0.016, respectively), and for ease of understanding the prompt message, which individuals with MS rated significantly higher than older adults did for *My MS Manager* and *MS self* (t (14) = 2.309, p = 0.038; t (17) = 2.728, p = 0.015, respectively).

Results of the semi-structured interviews confirmed the previous findings and identified additional barriers and facilitators to usability for two groups of participants.

Both groups identified navigation, especially navigation back to a homepage, as the main problem on all three apps. Two user groups had issues with finding the specific pages on *iHealth* and people with MS had this problem on *My MS Manager*. It was not clear whether both groups completed the task, two groups of participants needed additional instructions for using the apps, it was not clear if they saved an entry, and font and button sizes were too small for most of the users on all three apps. Older adults had problems with color contrast on all three interfaces, and issues with scrolling on *iHealth* and *My MS Manager*. This finding complemented the effectiveness results with help requests where I did not identify the usability problem with contrast in older adults. Therefore, the identified themes for usability problems (i.e., barriers to usability) matched across two groups of participants.

All the facilitators' categories matched between the two groups even though not all facilitators were identified in all three apps. For example, participants in both groups found emoticons on *MS Self* to be usable, color contrast on *My MS Manager* good enough, use of blood pressure cuff on *iHealth* very useful, and *MS Self* and *My MS Manager* were found to be simple and intuitive to some users. However, people with MS found swiping to be easy in all three apps, and older adults found it easy only in *MS Self,* and individuals with MS identified good color scheme in *MS Self* and *My MS Manager* and senior only in *MS Self*.

This study resulted in a set of evidence-based design recommendations to assist with the future development of mHealth interfaces for older adults, including people aging with disabilities. The navigation, finding the Home page and other pages within the interface, task completion, instructions, appropriate size of the fonts, buttons, and icons, high color contrast, and avoiding the use of scrolling and the picker represented the most important design elements that needed to be considered for the development of mobile interfaces for population of people aging with MS. Overall, both user groups identified the same categories of usability problems and the two groups found almost all specific issues with the interface. Therefore, the main points of the study and design recommendations that resulted from this user testing coould be generalized across the two groups of participants: an aging population and people aging with MS.

The study findings implied that the resulting design recommendations should be used as the crucial guidelines when designing mobile applications for older adults and those aging with disabilities. These design recommendations could be used to refine and prioritize the UDMIG, placing the related guidelines at the top of the list.

6.1.3.1.1 Strengths and Limitations

The main drawback of this study was an unequal number of participants in two user groups. However, the difference in the numbers of participants was minimal (i.e., ten older adults and nine individuals aging with MS). However, due to this disbalance in the number of participants, in addition to the number of help requests, I reported the frequency of those assists. Additionally, the sample sizes were large enough to identify usability problems with an accuracy rate of 95% (Faulkner, 2003).

Usability testing assessed the initial use of the tested applications and provided discoverability problems in its controlled setting (Sy, 2009). This study identified a large number of valuable design elements and their characteristics for an aging population and people aging with disabilities.

6.1.3.2 Refinement of the UDMIG to Include People Aging with Disabilities

I designed the initial UDMIG for an aging population only. It was not evident that these guidelines apply to the individuals aging with disabilities. Usability testing of the current mHealth apps and semi-structured interviews provided the main design recommendations for the development of mobile applications for an aging population and people aging with MS based on the identified crucial elements in three mHealth apps that acted as either barriers or facilitators to usability to both user groups. Additionally, the categories of usability problems and most of the individual issues were found in both groups of participants. I found that all seven design recommendations were present in the UDMIG v.2.0 as its guidelines. Thus, these design recommendations have been used to prioritize the UDMIG and to confirm the applicability of the guidelines to both user groups: an aging population and individuals aging with MS. Based on each UDMIG v.2.1 guideline, corresponding design criteria were created to guide the design of MS Assistant.

6.1.4 Design and Iterative Testing of MS Assistant to Validate the UDMIG

6.1.4.1 <u>MS Assistant Design</u>

I designed MS Assistant as a holistic app that provides the functional features identified in the formative user needs assessment study. Additionally, I designed the user interface of the mHealth app based on all UDMIG design criteria to provide universal usability with simple and clear interaction and navigation.

6.1.4.2 <u>Iterative Testing: Effectiveness of the Design Features in MS Assistant</u>

Iterative evaluation of the UDMIG v.2.1 through its application to the mHealth app design was conducted with the purpose to validate the design guidelines and to understand the limitations of expert review compared to the usability testing with the end-users in identifying usability problems in mobile apps. As the part of the iterative testing, I asked expert reviewers to evaluate the effectiveness of the design features in MS Assistant and suggest refinements. The results suggested that the expert evaluators rated well-implemented design characteristics of design features in the mHealth app. They identified some design elements that needed minor improvements and recommended possible refinements. I then redesigned MS Assistant based on these recommendations. Following the app refinement, I conducted usability testing of MS Assistant with individuals aging with MS to assess the effectiveness of the design features in the mHealth application, the effectiveness of the app, and satisfaction with the app. This was a second study, which was as a part of the iterative evaluation process following the expert review.

The strength of the expert review was that it was time-efficient in identifying the elementary and tactical problems that could be quickly addressed to improve the mobile interface (Six, 2009). This method was useful in rating the design against the guidelines and design criteria. However, usability testing that resulted in the perspectives of users was necessary to extract more in-depth data (Rubin & Chisnell, 2008). Experts were not familiar with the specific context of use as end-users are (Six, 2009). Therefore, they explored the surface of the problems. Overall, the combination of the expert review and usability testing (or interviews) with target subjects brought a greater range of results and ensured content validity (Naar-King, Ellis, Frey, & Ondersma, 2003; Six, 2009). In this study, I used mixed-methods design to inform the usability testing by using the results from the expert reviews (Greene et al., 1989). Specifically, expert review results were used to validate the UDMIG v.2.1 and inform the design of MS Assistant, which was further tested with its target population. The purpose of both studies that tested MS Assistant was the evaluation and validation of the UDMIG v.2.1 through its application to the mHealth app and the improvement of the app design by identifying usability problems and redesigning the app.

6.1.4.2.1 Expert review

The results of the expert review confirmed the effectiveness of design features in MS Assistant. This implementation of the guidelines to the design of the mobile app scored well. Ninety-four percent of the mean values of the participants' ratings were equal to 4 or 5. Expert reviewers provided some design recommendations related to minor usability problems in MS Assistant. Design changes and app redesign addressed the usability-related suggestions made by expert reviewers.

The mean of all the ratings for design features was within a range of 3.90 – 4.89. The only design feature rated as 3.90 and lower than 4 was represented by DE6b (i.e., this app provides the system which can detect the error and offer a prompt message for handling it). Participants agreed that the app provided a prompt message for handling an error. However, the prompts in that version of the app informed the users that they need to enter missing information and did not offer an option to skip certain fields. They made users fill out all the information on the page. Expert reviewers suggested that the prompt should be flexible and "offer options to submit data without all responses submitted." The second lowest mean rating (M_1, M_2=4.00) and the third one (M_3=4.20) were given to three design features because of the lack of tactile feedback due to the absence of the Taptic Engine in iPhone 6 model. Two design features had a mean rating of 4.22: IC8 "choice of linear navigation vs. random access," and IC13b "minimized steps (i.e., basic tasks)" because of the existence of the linear navigation, which increased the number of steps needed to navigate through the app. Participants recognized the importance of the linear navigation to older adults but wanted to document the lack of intuitiveness of this type of the navigation to younger adults. All other mean ratings of the design features were equal to 4.33 and above and there was no significant difference between those mean ratings and the highest mean rating of 4.89 given to three design features: IC6d "cursive and decorative fonts and use of all uppercase letters are avoided," IC9 "personalization to change my skill level from a "novice" to an "expert" user," and IC10a "configuration of the display settings to my needs and preferences." Therefore, these design features related to design criteria that were rated significantly lower than the best design elements had to be redesigned based on the recommendations of expert reviewers. Additionally, the second highest mean rating (M=4.80) was given to eight design features: DE1a 'large enough button size," DE4c "buttons in colors that stand out, and arranged in linear order," DE6a "easy reversal of my actions if I make a mistake," IC4a "the use of the picker is avoided," IC4b "scrolling text, especially horizontal formats, is avoided," IC5a "clear indication on the top of the page where the user currently is at any point of time," IC14a "visible spacing between the small buttons," and IC15 "main navigation buttons of equal importance at the bottom of the screen."

In addition to rating the design features, expert reviewers provided recommendations for the redesign of certain features. I grouped these suggestions into themes related to identified usability problems. Expert reviewers identified following nine issues with the interface through the UDMIG design criteria questionnaire in the order of its significance: navigation, labeling, the design of UI elements, feedback with buttons, keyboard, page layout, contrast, prompt, and font size. The feature with the highest frequency of usability problems (N=70%) was linear navigation and the problem with understanding that there is another way of navigation (i.e., random access) in 20% of participants. The next significant usability problem was related to labeling of certain functional features (e.g., education, emergency, energized, input, output, and speech) and had the highest frequency of usability problems of N=40% for term "education." The rest of the terms had a frequency of N=22.22% and less. Other usability problems had a very low frequency of usability problems with N=30% as the highest. For example, in the design of UI elements theme, 3 participants (N=30%) reported that Profile and Settings did not look like buttons and that those should be redesigned to stand out and look more prominent. Design of MS Assistant homepage in Adobe Illustrator presented in this document followed the guidelines strictly and made a distinction between the name of the app and Profile and Settings buttons on the first page. However, because of the limitations of the size of the top navigation bar in iOS, there was no space for the Profile and Settings icons due to the minimum font size dictated by the UDMIG v.2.1. The other issue with the design of UI elements was that top navigation bar icons that represent a title of the current page, including the weather icon, looked like buttons. Due to the limited size of the top navigation bar in iOS and the minimum font size required by the UDMIG, those icons looked the same as the Home button. Participants (N=20%) commented that the design of the slider should be changed because of the problems with motor control in individuals with MS and their possible use of the stylus. One participant thought that the numbers on the bottom should be moved to the top of the slider so that the finger does not block it. Additionally, participants reported a lack of vibration while tapping the buttons even though they understood the limitations of iPhone 6 due to the lack of the Taptic Engine, which provides the vibration while tapping the buttons that were included in later iPhone versions. Surprisingly, one expert reviewer "expected to double-click." However, the single tap was implemented throughout the app to conform to the design criteria IC13a (i.e., use a single tap throughout the app instead of double-clicking). One participant suggested providing spell check and page scrolling with the use of a keyboard. Scrolling was disabled throughout the interface because of the IC4c design criteria requirement. Participants suggested that "View Reports" button should be placed above "Email Reports" and that the spacing between the top navigation bar and large buttons (e.g., Manual entry, Week, Month, Year buttons) should be increased. Low contrast on the instructions pages was reported. Again, participants reported that after getting a prompt message the app should "offer options to submit data without all responses submitted."

Audio transcripts revealed additional usability problems, such as single tap, feature requests, miscategorization, lack of consistency, and lack of confirmation. For example, they suggested to specify the body area in Difficulties, to display the user's current weight in goals, to have louder sound feedback with the use of the buttons, to add MS experience within Profile and Resources to the list of News, Research, and Tips, to add the infobox to the View Reports page with "Select one or more buttons and choose whether you want Reports," to have the option to check the email address of the person who would get the reports sent by the user, and to clarify on the top of the Instruction page "what this page is" by possibly adding "Getting started," to have specific information about MS friends to distinguish between people with the same names, and to change the navigation in a case of two selections in a way that after making one selection the app takes you to that page, and then it takes you to the one-screen selection again to make the second one. One participant thought that after the prompt about sharing the personal information, Profile page should have that information written again on the top of the page. Additionally, participants commented about the miscategorization of the certain labels. Participants reported lack of consistency in the page layout regarding the selections on two pages in the View Reports and Email Reports. They had issues with the page design and navigation, such as multiple selections on a page, lack of another meal page after you go through one.

I did not address the major issues reported by a larger number of expert reviewers during the app refinement stage due to its consistency with the UDMIG, except for the problem with prompt messages. Additionally, a small number of participants identified other issues with the interface, which were minor usability problems that I addressed in the redesign stage of the app. In summary, the expert review identified one major usability problem that is related to the UDMIG and many minor issues with the mobile app. This finding confirmed that the expert reviews extract basic and tactical usability problems that can be quickly addressed to improve the mobile interface (Six, 2009). Expert reviewers did not know the specific contexts of use and explore the surface of the problems (Six, 2009). Therefore, this study identified the need for the next step, which would be usability testing of the mHealth app with the end-users who would bring their perspectives that are necessary to extract more in-depth data.

6.1.4.2.1.1 Strengths and Limitations

One of the benefits of this study was time-efficiency needed to test the design features, identify the basic usability problems, and redesign the mHealth app so that it can be further tested with the end-users. The study was effectively conducted with ten expert reviewers and resulted in the identification of the most obvious usability problems. The results of the study were used to improve the design of MS Assistant to test it with the end-user population.

Based on the results of the expert review, the ratings of the UDMIG design criteria questionnaire identified only major usability problems with the interface compared to design recommendations that identified a larger number of issues. However, the ratings allowed for the prioritization of the usability problems and identification of the facilitators in addition to the barriers to usability.

The drawback of the study was the depth of the analysis of the usability problems that can be identified by the experts compared to those issues with the interface that could be found by the end-users. Expert reviewers found one major issue and some basic usability problems with the app. To acknowledge the expertise and knowledge of the experts as well as the needs and wants of the end-users, I have conducted usability testing after the expert review to include more in-depth analysis of the usability of the app and to understand the context of use by the end-users.

6.1.4.2.2 Redesign of MS Assistant

I redesigned MS Assistant based on the suggestions of expert reviewers. Specifically, I identified usability problems through the UDMIG design criteria questionnaire and audio transcripts. The questionnaire identified a single most critical issue with the interface and others that were not related to the UDMIG or were related to implementation problems. For example, I redesigned the prompt to allow users flexibility in navigation and an option to enter data they want, and not necessarily all data. However, three design features were rated second and third lowest due to the lack of the tactile feedback. Participants would appreciate having vibratory feedback implemented within an app, but they understood the limitations of iPhone 6 model and the lack of the Taptic Engine. There was no redesign related to these three rated design features rated low. Additionally, two design features were rated next lowest because of the existence of the linear navigation, which increased the number of steps needed to navigate through the app. Design criteria IC8 required a choice of linear vs. random access navigation to benefit the aging population of users and slow down a pace of interaction. Therefore, I did not redesign this design feature of the app to follow the UDMIG.

In addition to the results from the ratings, I grouped identified issues with design features and related design recommendations into themes. Based on these recommendations, I redesigned the app. For example, the second major issue following linear navigation was the naming of certain functional features, such as education, emergency, energized, input, output, and speech. I renamed those features to solve this minor usability problem. Participants suggested that Profile and Settings buttons on the homepage should "look like buttons" by adding a black border to them, relevant icons, or background color so that those look like the other buttons on the home page. Because of the limitations of the top navigation bar, I took out the name of the app and added Profile and Settings icons. Headers were redesigned to look different than the home button by changing the color of the icon to match the color of the current page. The numbers on the bottom of the slider were moved to the top of it so that the finger does not hide the selected values. The slider as a feature was left to be tested with the end users. I added spell check and page scrolling with the use of a keyboard. I moved "View Reports" button above "Email Reports," and I increased the spacing between the top navigation bar and large buttons. I added specific information about MS friends to distinguish between people with the same or similar names.

6.1.4.2.3 Usability Testing with People Aging with MS

The results of the usability study with people aging with MS confirmed the effectiveness of the design features within MS Assistant. The application of the guidelines to the design of the mHealth app scored well. Most of the participants favorably agreed that the design features were effective in producing universally usable interface. The majority of the mean values of the participants' ratings were equal to 4 or higher. The mean values of the ratings were equal to 4.05 and above. Thus, participants rated all design features highly in MS

Assistant. The design criteria DE2b "this application provides system feedback for my actions, such as a beep when pressing a key or an error message for an invalid input value" had the lowest mean of the ratings (M=4.05). Participants who rated it low did not hear the sound when pressing the buttons. The sound feedback after pressing a key is a smartphone device system feature, and it cannot be addressed from the design point. The second lowest rated design feature was characterized by IC1a "the same means of use for all users, by eliminating specialized design and language" (M=4.14). Five participants were not sure how to rate the feature because they wanted to have MS displayed on the main app icon to differentiate this mHealth app from others on the smartphone, which was opposed to the design guideline, and rated it 3. The next lowest mean rating (M=4.23) was given to IC2d "more than one way to go to different pages while keeping the consistency." Some participants were not aware that they could navigate through the interface using both random access and linear navigation. This could be simply solved by adding the information about the two ways of navigation to instructions. Mean rating of 4.27 was given to DE2a "feedback about a confirmation of my activity and a current state" because some participants misunderstood the script. Mean rating of 4.32 was given to IC5b "related information in a group, and the most frequent operations highest on the page" because a few participants could not recall the layout of the page and were not clear how to rate the feature. The previous design features were significantly different from the highest mean rating and the ones related to the UDMIG needed refinement (e.g., adding instructions about two ways of navigation and adding the feature in settings that would allow users to increase the volume of the button feedback sound). All other design features were rated very highly (M=4.41 and above) and were not significantly different from the highest mean rating that was given to IC7a "understandable reading level of text material" (M=4.86). The next two highest ratings (M=4.82) were given to IC13a "use of a single tap throughout the app instead of double-clicking," IC10a "configuration of the display settings to my needs and preferences, such as text size, contrast," and IC5a "clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games)."

In addition to rating the design features, participants completed ten tasks on MS Assistant. I calculated completion rates (M = 76.82%, SD = 20.79%; range = 40% to 100%). One of the two participants with the lowest completion rates was asking for help whenever unsure about the next step, which resulted in the largest number of help requests (n = 23) and the low completion rate.

Moreover, video recordings revealed total number of errors (n=205, M = 9.32, SD = 7.66; range = 0 to 32), and total number of help requests (n=101, M = 4.59, SD = 5.92; range = 0 to 23). The participant with the largest number of errors was an older adult who was the only one who did not have prior experience using the touchscreen devices. One-third of their errors were due to the problems with the touchscreen issues and slips. I categorized the errors into common themes and identified all usability problems with the app, which participants encountered during the interaction with the user interface. There were three main usability problems in the mHealth app: issues with the navigation, slider, and the button design, which included the page layout. For example, the script asked the participants to enter a mood, symptoms, energy level, sleep quality and duration, activities, and diet without telling them where to do it. I was testing the intuitiveness of the app's main functional feature (i.e., Diary), which had the purpose of collecting the self-reported and tracked health and wellness data. Thus, some participants got confused about where to enter new data, which I coded as an issue with navigation. Additionally, participants encountered problems with entering difficulty, finding MS news, measuring the blood pressure, finding the healthcare provider's contact information, entering the personal information, and changing the text size. Some participants had a problem with understanding the use of "Add …" buttons (e.g., "Add difficulty," "Add contact"). They were using these buttons for the navigation and entering the data instead of entering new symptoms, new difficulties, new contacts, and new games. Only four participants had problems with the lack of understanding of the sequence required to navigate through the app due to the linear navigation using Next and Back buttons. However, when I explained the reason for having the linear navigation and double selection using Next and Back buttons, they understood its importance and thought it was easy to learn. Two participants had issues with the understanding that double selection provides one page for each selection. However, the interface was designed to provide consistency and to follow the design guidelines. The second major issue with the app was the lack of understanding of how to use the slider and the difficulty using it. Once participants understood how to use it, the majority of them did not have any problems with the slider. The slider can be replaced with a text box or a few buttons when there are a few options to choose from. The last major issue was the design of the buttons and icons and their location on the page relative to other design elements on the same page. Some participants had problems understanding that "Manual Input" button is an actual button and not the title of the page due to its location at the top of the page. Interestingly, the non-clickable image of the use of the blood pressure monitor looked like a button to one participant, an icon that represented a phone contact and top navigation bars looked clickable to a few participants. "Manual Input" button should be placed at the bottom of the page to solve this problem and to conform to the UDMIG more (IC14c "the location of the buttons should be near the center or the bottom of the screen"). Additionally, there was a number of minor usability problems with the mobile app. For example, the issues with the keyboard included the problem with the small size of the keys and "Done" button. This usability problem could be solved by initially increasing the keyboard even more and adding that feature in settings. A few participants had a problem with reading and understanding the information presented in the prompt messages due to the small size of the prompt message and small font size. Lastly, one participant did not understand whether the current or the goal weight were required to enter in the goal weight.

I categorized the help requests into the common themes to identify the most important usability problems with the app. One of the two participants with the highest number of assists was the only one who did not have prior experience using touchscreen devices. Participants identified issues with the navigation (i.e., entering new data, lack of understanding of the sequence required to navigate through the app, and double selection) and slider (i.e., lack of understanding how the slider works and difficulty using it) as the major usability problems. Additionally, a few participants asked for assistance due to the lack of understanding of how to use the keyboard and the small size and the location of "Done" button on a keyboard. A few participants asked for help because "Manual Input" button looked like a title on the page and due to the existence and the layout of the second page in Reports. Lastly, one participant had a problem understanding the page information and requested help when wanting to change the value of the calories, which should not be changed by the users.

As expected, audio transcripts revealed additional usability problems, such as feature requests and other minor issues. Features requests included a drop-down menu with MS types instead of the text box; buttons instead of the text box and drop-down menu because the drop-down is hard to use; an option to add mood, symptoms, difficulties, activities and heat in Diary multiple times per day, as well as an important event that can affect the symptoms; to merge Vitals and Goals and have current values and goals within the same feature; to add diet to goals; to have both current weight and a goal together; to add a question "Are you on a good therapy medication?" because that can cause new symptoms; to have a photo, personal information, and medications in one place, that can substitute current MS cards; to see the progress after they set up the goals; the reminders for measuring blood pressure; to select multiple moods; to search for people of a certain demographic in MS Friends; to speak with a friend that knows another language in MS Friends; to share the name of a doctor in personal information; to have icons instead of the comment section for the side and part of the body for symptoms; sleep notes; more adjectives for sleep quality; and number of times one wakes up during the sleep. Minor issues included a problem with the term "Emergency contacts" that should be renamed into "Health contacts" or "Frequent contacts," and with "Excited" that should be renamed into "Fabulous." A few participants suggested improvements to the design and the size of the icons (e.g., Display and Sound icon in Settings, the size of Profile and Settings icons). One participant recommended to add an instruction about how to change novice to expert user mode and to have "more conversational" content in bullet points that answers "Why?" there is a need for the specifics within the instructions. Lastly, one participant asked how to write in the text box, and one commented that Settings should be in a different color than grey because of the use of bright colors throughout the app.

Overall, the major usability problems identified by the end-users were low sound feedback with pressing the keys, lack of understanding that there were two ways of navigation, issues with the navigation, lack of understanding and difficulties using the slider, button design with the page layout, and feature requests. There were additional major issues reported by larger number of end users that were non-related to UDMIG (i.e., IC1a "the same means of use for all users, by eliminating specialized design and language") or were related to the misunderstanding of the script (DE2a "feedback about a confirmation of my activity and a current state") or the lack of recollection of the page information (IC5b "related information in a group, and the most frequent operations highest on the page"). Additionally, a small number of participants identified other minor issues with the interface. In summary, usability testing with the users identified six major usability problem and many minor issues with the mobile app. This finding confirmed that usability testing identified a larger number of major usability problems with the interface and extracted more in-depth data within its context of use.

6.1.4.2.3.1 Strengths and Limitations

Based on the results of the usability testing, the ratings of the UDMIG design criteria questionnaire identified only part of the major usability problems compared to video transcripts that identified additional critical issues with the interface. However, the ratings identified different usability problems than the video transcripts did.

One limitation of this study was that the participants self-reported their functional limitations. Some of them had too many limitations, and they were not sure which ones to report and reported only the major ones. A number of participants reported only physical limitations and may have forgotten to self-report cognitive impairments. Additionally, fatigue is very common in individuals with MS. However, only six participants self-reported having this symptom. Therefore, the actual number of their functional limitations was likely to be greater than or equal to the self-reported numbers (Figure 23 and Table 37).

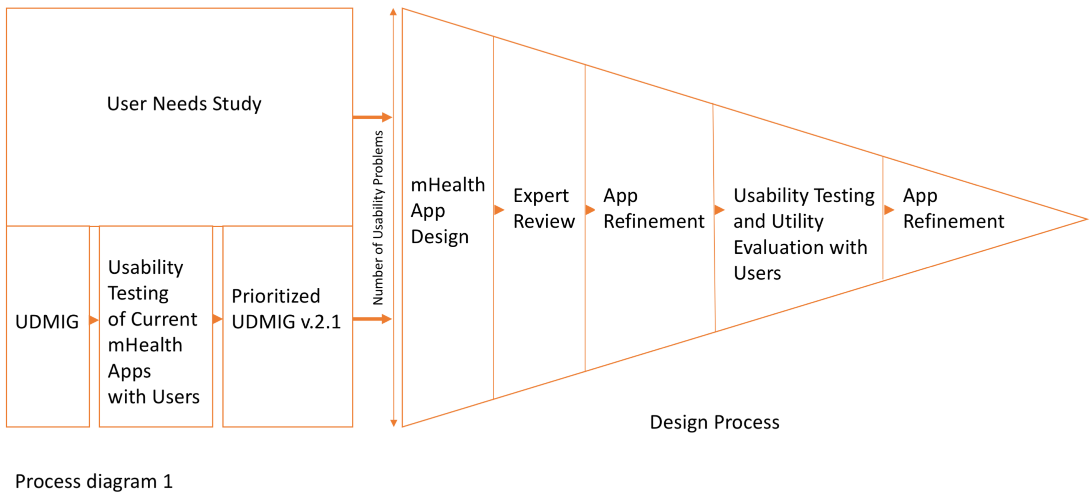
The drawback of the scripted usability testing was that the participants who used new mobile app had a harder time navigating the interface while reading the script, remembering and entering the prescribed data than if they were using the app on their own to record the data they want to enter. People who experience cognitive limitations have problems with remembering new information. In that way, the scripted usability testing becomes harder for individuals with MS who have cognitive impairments. The results of this type of study report greater number of errors than those of the unscripted field study in which participants are free to use the mobile app in their natural setting to enter their data.

6.1.4.2.4 Difference Between Results of the Expert Review and Usability Testing

I used the expert review as a time-efficient method to identify the fundamental usability problems, which can be addressed in a fast manner to improve the mobile application (Six, 2009). The expert review identified only one major usability problems and many minor issues with the mobile app. I learned that knowledgeable experts can recognize most obvious and basic issues with the app that can be quickly and easily addressed, and that I needed to gather more useful feedback and input from the end-users to better understand the difficulties they face while using the mobile applications. Compared to this research method, usability testing identified six major usability problems and some minor ones. All six issues with the interface were new ones in addition to those found by experts because the major problem in the expert review was addressed by refining the mHealth app. Moreover, the minor usability problems found by the individuals aging with MS were not identified by the experts. This was in part due to the refinement stage of the app that included the redesign of MS Assistant based on the findings of the expert review. Thus, usability testing that resulted in additional in-depth data due to the perspectives of users was essential to understand the usability of the mHealth app and to validate the design guidelines.

The findings of both studies confirmed the that the expert review can reveal only certain essential usability problems in mobile user interfaces limited by the extent of the experts' knowledge (Six, 2009). Usability testing with the users was needed to understand the specific context of use and gather more thorough results. I recommended a combination of the expert review and usability testing with a target population that would result in a greater range, number, and depth of outcomes and identified issues with the interface. Researchers found that this type of mixed-methods study design ensures content validity (Naar-King, Ellis, Frey, & Ondersma, 2003; Six, 2009).

Figure 26 presents the two process diagrams: the first one illustrates all the design stages of this research study that helped to design and to evaluate the UDMIG and to understand the utility of the mHealth application for individuals aging with MS; the second one shows a proposed process diagram when designing mobile apps for older adults, individuals aging with disabilities, and those with chronic conditions. However, when designing for other chronic conditions and disabilities, the prioritized design guidelines in the UDMIG might be different based on distinctive functional abilities and should be tested with their target population. Additionally, an expert review could be used to identify the basic issues if time permits. This research method is quick and allows for a fast redesign of the mobile app due to the small quantity of the results it provides.



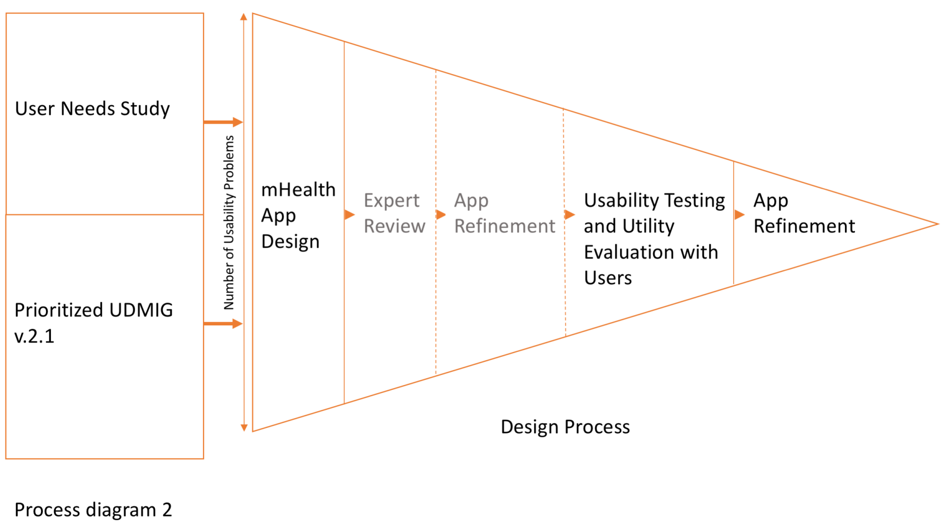


Figure 1 – Process diagram 1: the design stages of this research project, Process diagram 2: proposed design process for the development of mobile applications for people aging with and without disabilities and those with chronic conditions

I recommend including experts as knowledgeable participants that can identify and offer valuable redesign insights in a fast and educated manner to provide cost-efficient study and app refinement. Alternatively, another research method could be used to test the mobile app in a quick and effective way. If time does not permit experts to participate or another method to be employed, usability testing with users should be conducted to identify the most important usability problems and sometimes offer design recommendations. This stage of the design process represents the crucial part of the study that would help designers and researchers understand the most important aspects of the mobile application design. However, most of the design choices following the usability testing will typically depend on the researchers and designers.

6.1.4.3 Effectiveness of the Functional Features in MS Assistant

Additionally, usability testing evaluated the utility of the mHealth app and usefulness and importance of the functional features with the purpose to confirm and further clarify the needs of people with MS for self-management of their health and wellness. The study results confirmed the usefulness and importance of the functional features in MS Assistant for people aging with MS. Participants found all the implemented functional features highly useful and important. The utility and importance of all the features were rated above 4.

The feature with the lowest mean rating for usefulness was MS Friends (i.e., social support and community forum), and the one with the highest mean rating was Settings (i.e., customization within the app). The difference between the between these two mean ratings was found statistically significant ($t(21)=3.225$, $p=.004$). Games (including VR games) and MS-related resources got the second lowest mean ratings and the difference between that rating and the highest mean rating for was statistically significant ($t(21)=2.857$, $p=.009$; $t(21)=1.901$, $p=.071$, respectively).

The least important feature was Games (i.e., classic and VR games that improve cognitive functioning and balance), and the most important one was Settings (i.e., customization within the app). The difference between these two mean ratings was statistically significant ($t(21)=3.048$, $p=.006$). Personalization within Profile feature got the second lowest mean ratings. The difference between the mean rating of this feature and the highest mean rating for Settings was found statistically significant ($t(21)=2.746$, $p=.012$). The second most important functional feature was having one app that integrates all other features and serves as a comprehensive tool for the management of the condition and the next important feature was Emergency Contacts.

Overall, participants found the main functional features that represent the purpose of the app, which is a health and wellness self-monitoring including self-reporting and tracking of data, to be its most useful functionalities. Additionally, individuals aging with MS tested in this study recognized the importance of the customization, having one holistic mobile app for the health self-management, and an immediate response in a case of an emergency.

6.1.5 Validation of the UDMIG v.2.1

The UDMIG v.2.1 were validated through an iterative assessment of the guidelines and its application to the design of MS Assistant. Two evaluations were conducted (i.e., an expert review and usability testing with the end-users) to evaluate the effectiveness of the design features in MS Assistant and to validate the UDMIG v.2.1. Based on the results of the two summative evaluations, the UDMIG v.2.1 and their application to the design of MS Assistant were validated. These studies reported that the UDMIG applied to the design of MS Assistant meet the usability requirements of individuals aging with MS.

A small number of issues with the mHealth app were found that were related to minor usability problems with the user interface, which were grouped into three categories. Issues with the *implementation* and usability problems *related to the UDMIG* that were not effective were two groups of problems that validated the UDMIG. In addition to these usability problems that validated the design guidelines, participants identified certain issues *non-related to UDMIG*. For example, usability problem related to *implementation* was the issue with “Manual Input” button design and page layout, which looked like a title of the page and not an actual button. By moving the button to the bottom of the page and by complying to the design criteria IC14c (i.e., the location of the buttons near the center or the bottom of the screen), the design of the app would be improved and more usable, which would further validate the design guidelines. Another example of the poor *implementation* was the problem with reading and understanding the information in the prompt messages due to the small font size. Throughout the whole interface, I followed closely design criterion IS6a (i.e., whenever possible use 14-point and bigger serif or sans serif fonts and use at least 12-point when not). However, due to the iOS limitations of the prompt message size, the font size on the prompts was constrained. These system limitations further validated the UDMIG since participants did not found usability problems related to font size within the app. An example of usability problems *related to the UDMIG* that were not effective was an issue with navigation due to the lack of understanding of the sequence required to navigate through the app. A few participants expected a particular page to open after they made a selection, which could be solved by adding an explanation about the linear navigation to the instruction page. The use of linear navigation and random access was implemented based on the UDMIG. The participants understood the importance of having two ways of navigation that benefit an aging population and thought that it was easy to learn. Another usability problem *related to the UDMIG* was that top navigation bar icons looked clickable to a few participants. These icons with the text description represented the page and gave information about the users' location within the interface. The icons with the text and their location on the page were designed based on the UDMIG. Therefore, the problem might have been in the overall design and layout of the page.

Additionally, usability problems that were *non-related to the UDMIG* should be added to the design guidelines to address the additional issues identified by the users that the UDMIG missed to include. For example, the issue with navigation because of the confusion about where to enter new data due to labeling could be solved by paying the close attention to the terminology used for functional features based on the expectations of users. This issue should be added to the design guideline "IS6. Maximized "legibility" of essential information" to augment the UDMIG. User needs studies should be used to identify the precise and familiar terminology for end-users. Another example of issues *non-related to the UDMIG* was a lack of understanding and difficulty using the slider, which can be solved by replacing the slider with another design elements, such as a few buttons. It should be added to the design guideline "IS4. Simple and natural use" to further reinforce and improve the guidelines.

6.2 Significance

The significance of the project lies in the contribution to the body of knowledge on the design and validation of integrative universal design guidelines, UDMIG v.2.1, to guide and improve the design of mobile applications for an aging population with and without disabilities. In addition, the project identified the needs and concerns of individuals aging with MS related to the condition self-management and provided the design recommendations for the development of mHealth applications for people aging with MS that meet those needs. It specified the set of the usability recommendations to inform the design of future mobile apps for individuals aging with disabilities. Moreover, it described the design and evaluation of the evidence-based app MS Assistant, which is an innovative mHealth application that provides a personalized and customizable interface within a holistic system for self-management of the condition. Lastly, the project proposed a design process for the development of mHealth applications for individuals aging with and without disabilities diagnosed with various chronic conditions.

The immediate output of these research activities was the validated UDMIG v.2.1 to include people aging with disabilities and to promote universal usability. The secondary output of this research project was a mobile health and wellness self-management application for individuals aging with MS.

Finally, this work contributed to design research with the validated design guidelines for the design of mobile applications for a population aging with and without disabilities. It advances the technology uses with the design recommendations that support the inclusion of the population of users with its varying and ranges of abilities and limitations. The research project illustrated and described a process diagram for the design of mobile apps for older adults, individuals aging with disabilities, and those with chronic conditions.

6.3 Future Research

In addition to developing and validating the mobile interface guidelines for the individuals aging with disabilities, I designed an evidence-based holistic and adaptive mHealth application for people aging with MS to increase their understanding of the condition, to better self-manage the symptoms, and improve their QOL. MS Assistant represented the universal design platform for health and wellness information for individuals aging with MS. With its universal usability approach, the study resulted in a unique and prescriptive design process that can be expanded and applied to the development of future mHealth applications for an aging population, those aging with disabilities, people diagnosed with chronic conditions, and ultimately to all people. This research study helped to advance the understanding of the design of individualized support for people aging with chronic conditions through mobile applications.

The application of UDMIG v.2.1 to a mobile health and wellness app design was presented to illustrate and showcase the possible uses of the guidelines for a population of individuals aging with disabilities. mHealth application for individuals aging with MS, MS Assistant, was developed for this purpose. User needs for self-management of health and wellness were identified to design the mHealth app that meets the needs of its end-users. An important outcome of the research study was the design process and diagram that can be used for future mobile health and wellness technologies. The design of the mHealth apps should be informed by the user needs studies that specify the utility (i.e., functionality) and by the UDMIG that guide the usability of the application. However, the mobile app needs to be tested to evaluate both condition-specific health information based on user needs (i.e., utility) and interface design based on the UDMIG (i.e., usability) of the mobile app. This should be done through an iterative evaluation. I used an expert review as initial testing of the app due to its fast nature to identify the most basic issues. Another type of testing that provides quick and valuable insights could be done instead of an expert review. Moreover, usability testing and utility evaluation should be conducted to gather the crucial feedback from the end-users. This was the most important stage of the design process that provided the most significant findings to inform the redesign of the app to be useful and usable to its users.

This project presented a proof of concept study, which should in future employ increased size and diversity of participants to ensure the validity and generalizability of the design guidelines (Shneiderman, 2016). The future work should test the fully developed MS Assistant over time to understand the usability, acceptance, and adoption of this mHealth app. A future investigation should be conducted with an aim to understand the type of information other stakeholders, such as healthcare providers, family members, and professional caregivers need. This study should result in a more comprehensive set of recommendations required to accommodate the design of mobile applications for people aging with MS and other potential end-users.

This case study focused solely on the health and wellness self-management needs of individuals aging with MS related to the mobile technologies. However, the findings of this study could be generalized and applied to the design of mHealth apps for other chronic conditions if the appropriate minor adaptations are conducted to account for the differences between MS and the chosen condition. I found that health and wellness tracking and self-reporting were core features of the mHealth apps. Participants wanted personalized information and insights about their condition and self-management. Additionally, they wanted to share this information with certain people, especially with their healthcare professionals for the purpose of time-saving and efficiency. Education, reminders, and community forum were found incredibly useful to our participants and supported by the previous studies for other conditions (Mendiola et al., 2015). In our study, I found that telehealth, VR games, and condition-specific exercises present potential valuable features in health apps. Although popular and studied functional features, such as goals and gamification (i.e., achievements) were not discussed by the participants in this study, those two functionalities were proven to be valuable to end-users (Mendiola et al., 2015). Additional studies should explore the needs for the health and wellness self-management among individuals with other chronic conditions and confirm the generalizability of this study findings.

APPENDIX A. SET OF INCLUSIVE DESIGN GUIDELINES, UDMIG V.1.0

Universal design (UD) principles	**Guidelines**
Principle One: Equitable Use The design is useful and marketable to people with diverse abilities.	1a. Provide the same means of use for all users: identical whenever possible, equivalent when not. 1b. Avoid segregating or stigmatizing any users. 1c. Provisions for privacy, security, and safety should be equally available to all users. 1d. Make the design appealing to all users.
Principle Two: Flexibility in Use The design accommodates a wide range of individual preferences and abilities.	2a. Provide choice in methods of use **to allow users to feel they are in control (Shneiderman, 2000).** 2b. Accommodate right- or left-handed access and use. 2c. Facilitate the user's accuracy and precision. 2d. Provide adaptability to the user's pace.
Principle Three: Simple and Intuitive Use Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.	3a. Eliminate unnecessary complexity. 3b. Be consistent with user expectations and intuition. 3c. Accommodate a wide range of literacy and language skills. 3d. Arrange information consistent with its importance. 3e. Provide effective prompting and feedback during and after task completion. **3f. Design dialogs to yield closure (Shneiderman, 2000).**
Principle Four: Perceptible Information The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.	4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information. 4b. Provide adequate contrast between essential information and its surroundings. 4c. Maximize "legibility" of essential information. 4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions). 4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations. **4f. Design for multiple and dynamic contexts (Shneiderman, 2000).**
Principle Five: Tolerance for Error The design minimizes hazards and the adverse consequences of accidental or unintended actions.	5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded. 5b. Provide warnings of hazards and errors. 5c. Provide fail safe features. 5d. Discourage unconscious action in tasks that require vigilance.
Principle Six: Low Physical Effort The design can be used efficiently and comfortably and with a minimum of fatigue.	6a. Use reasonable operating forces. 6b. Minimize repetitive actions. 6c. Minimize sustained physical effort.

Principle Seven: Size and Space for Approach and Use Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.	7a. Accommodate variations in hand and grip size.

Source: (Ruzic Kascak et al., 2014)

The application of the inclusive design guidelines is explained bellow:

Principle One: Equitable Use

1a. Provide the same means of use for all older adults to eliminate the need for specialized design.

1b. Avoid the use of the signage for specialized design.

1c. Fast and secure saving of all data and performed readings to be resumed later without any loss is a vital issue.

1d. Design for enjoyment (Gong & Tarasewich, 2004). Important part of an enjoyable experience is aesthetics and fun (Gong & Tarasewich, 2004; Shneiderman, 2004).

Principle Two: Flexibility in Use

2a. Speech input and output are a viable alternative for small devices as smartphones with small touch buttons, which could be limiting for older adults with dexterity issues, arthritis, and visual impairments (Fjeldsoe, Marshall, & Miller, 2009). They need to feel that they are in charge of the system and have the system respond to their actions, rather than think that the system is in control.

2b. Allow for preference for the locations of the touch buttons for left- or right-handed users.

2c. Allow for variations between the older adults' preferences. They have different usage patterns, preferences, and skill levels. Design for plasticity, facilitating transformation of content. Adding features for novices, such as explanations, and features for experts, such as shortcuts and faster pacing, can enrich the interface design and improve perceived system quality.

2d. Mobile environment provides a more rapid pace, which needs to be adapted to the older adult's abilities. Provide multilayer interface that enables novice users to begin with a limited set of features at the first layer (Shneiderman, 2003). Users can move to higher layers when needed. Enable frequent users to use shortcuts (Gong & Tarasewich, 2004).

Principle Three: Simple and Intuitive Use

3a. Older adults are annoyed by tedious data-entry sequences, difficulty in obtaining necessary information, and inability to produce their desired result. Sequences of actions should be organized into groups with a beginning, middle, and end (Gong & Tarasewich, 2004).

3b. Consistency of the mobile health application should be applicable to multiple platforms and devices (e.g., consistent sequences of actions in similar situations, color, layout, capitalization, fonts, and similar, and identical terminology used in prompts, menus, and help screens). Older adults do not want surprises or changes in familiar behavior (Shneiderman, 2004). Use familiar language, similar to real world logic and dynamics (Leonardi, Mennecozzi, Not, Pianesi, & Zancanaro, 2008). Familiarity is implicitly stated within the guideline 3b. Design round shaped touch buttons.

3c. Allow for personalization (L. Kascak, Rebola, et al., 2013a).

3d. Design for top-down interaction. When presenting large amounts of information multilevel or hierarchical mechanisms should be used to reduce distraction, interactions, and potential information overload.

3e. Every operator action should have a system feedback, such as a beep when pressing a touch button or an error message for an invalid input value (Gong & Tarasewich, 2004). The feedback should be informative, substantial, and understandable by the user. Frequent and minor actions, can have modest response, and infrequent and major ones can have more substantial response.

3f. Interface should provide older adults with the satisfaction of accomplishment and completion, a sense of relief, and an indicator to prepare for the next group of actions.

Principle Four: Perceptible Information

4a. Reduce the short-term memory load. UIs should require very little memorization during the task performance (Gong & Tarasewich, 2004). Do not use UIs in which users must remember information from one screen and use that information on another one (Shneiderman, 2004). Older adults deal with more distractions in the mobile environment because their current activities may move their focus and suspend their primary task of interacting with the health mobile application. When they need to focus on more than one task, as when they are monitoring their vitals and reading the data from the application, mobile application may not be the focal point of their current activity. UI should not demand too much attention to distract older adults from more important task of taking their daily vital measurements. Design UIs to require as little attention as possible (e.g. design hands-free and eyes-free interaction, provide both sound and tactile outputs in addition to visual displays of the information). Design for limited and split attention.

4b. Enhance contrast (e.g., visual, auditory, cognitive) between the essential information and the background.

4c. Use minimum 14-point font size and sans serif type of fonts. Small text sizes may work well inside the homes, but these become unreadable in bright sunshine or in dimly lit spaces. Provide visibility, contrast, and clarity to important elements. Use high contrast wherever possible.

4d. Make clear instructions (e.g., Press Next first).

4e. Enable the use of required assistive devices.

4f. Usability of a health application can change based on different context factors (e.g., environmental conditions vary depending on the time of the day and season; social factors). In the presence of certain people or at some places, older adults may feel uncomfortable speaking aloud or the use of voice input might be restricted. In conditions of bright sunshine or in dimly lit spaces contrast and reading the text become an issue. Situations when users have one or both hands occupied while using a mobile device need to be considered as well. Context awareness, self-adapting functionalities, and/or universal control feature, which would work regardless of the context and environment, should be implemented. Derive input indirectly from the user.

Principle Five: Tolerance for Error

5a. Need for the more rapid pace of interaction in the mobile environment makes an error prevention one of a great importance. The physical design of mobile devices needs to be considered here, because smaller sizes of the touch screens make the proximity of buttons to each other as a potential for error. Gray out menu items that are not appropriate and do not allow alphabetic characters in numeric entry fields.

5b. Although Boulos, Wheeler, Tavares and Jones (Boulos, Wheeler, Tavares, & Jones, 2011) recommend suppressing all the error pop-up messages to avoid showing any system error to the user, Principle five suggests providing warnings of errors to minimize hazards and adverse consequences of accidental and unintended actions.

5c. Easy reversal of actions needs to be available to older adults (e.g., a single action, a data-entry task, or a complete group of actions, such as entry of a name-address block). This relieves anxiety and encourages exploration of unfamiliar options. Offer simple, constructive, and specific instructions for recovery after the error (e.g., users should not have to retype an entire name-address form if they enter an invalid zip code, but rather should be guided to repair only the faulty part). Errors should leave the system state unchanged, or the UI should give instructions about restoring the state.

5d. Unconscious actions in tasks that require undivided attention should be prevented (Sanford, 2012).

Principle Six: Low Physical Effort

6a. Frequent users have a need to reduce the number of interactions and to increase the pace of interaction. Time is more important to a mobile device user, which leads to a need to reduce the number of operations needed to perform regular and repetitive tasks.

6b. Avoid the use of physical force (e.g., use monitoring and tracking that do not require input from the user).

6c. Minimize simultaneous and repetitive actions (Sanford, 2012).

Principle Seven: Size and Space for Approach in Use

7a. Use large touch screens buttons to accommodate users with dexterity issues.

APPENDIX B. UDMIG V.2.1

Design Elements Guidelines

1. **Accuracy and precision.** Facilitate the accuracy and precision required to accommodate different abilities, preferences, situations, contexts of use, ages, novice and expert users, and enhance users' experience. Screen characters and targets should be conspicuous and accessible (e.g., font size should be 12-point and higher (Finlayson, 2002), the button size is at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017)). Based on the WCAG 2.0 recommendations (WebAIM, use contrast ratio of at least 4.5:1 and preferably of 7:1. 3D and VR displays may induce spatial confusion in older adults, which may require greater investment in working memory to resolve. However, with guided training and practice older adults may benefit from 3D interactive environments (Czaja & Sharit, 2012). Provide at least 50:1 contrast (e.g., black text on white background) (Fisk et al., 2009). Make sure that color discriminations can be made easily by signaling important information using short wavelength (blue-violet-green) contrasts, using black on white or white on black text, avoiding colored and watermarked backgrounds for display of text (Fisk et al., 2009). Avoid style sheets that prevent users from increasing the font size with the browser software (Fisk et al., 2009).
2. **Informative feedback.** Provide informative feedback for actions and task completion to confirm proper use. For every operator action, there should be some system feedback (Shneiderman, 1986), such as a beep when pressing a key or an error message for an invalid input value. For frequent and minor actions, the response can be modest while, for infrequent and major actions, the response should be more substantial (Gong & Tarasewich, 2004). It needs to be understandable to

the user (Gong & Tarasewich, 2004). Have feedback about task completion, confirmation of activity, and the current state (Fisk et al., 2009). Provide a text description for each icon (Johnson & Finn, 2017).

3. **Choice in methods of use.** Provide different inputs and choices of input to accommodate variations in abilities, preferences, situations, and contexts of use. Viable alternatives for mobile devices are speech input, replacing the text or graphics, tactile input (Poupyrev, Maruyama, & Rekimoto, 2002), and hands-free and eye-free interaction (Gorlenko & Merrick, 2003). Eye-free interaction provides the greatest freedom of movement as visual attention constrains body movement (Gorlenko & Merrick, 2003). Allow for personalization to accommodate differences in usage patterns, preferences, abilities, and skill levels (Gong & Tarasewich, 2004). In addition, users of mobile devices often need to focus on more than one task (Kristoffersen & Ljungberg, 1999), and mobile application may not be the focal point of their current activities (Holland, Morse, & Gedenryd, 2001). Mobile devices that demand too much attention may distract users from more important tasks. Interfaces for mobile devices need to be designed to require as little attention as possible (Poupyrev et al., 2002). Use speech recognition control and input when users are very restricted in manual dexterity and the ambient noise level is low in the environment (Fisk et al., 2009).

4. **Minimization of hazards and unintended actions.** As far as possible, design the system so the user cannot make a serious error (Shneiderman, 1986). Provide warnings of hazards and errors to ensure safety and prevent inadvertent mistakes/outcomes (Sanford, 2012). Discourage unconscious actions in all tasks to prevent adverse outcomes. Design should minimize hazards and unintended actions that could have unwanted outcomes (e.g., "Are you sure?" prompts) (Fisk et al., 2009; Sanford, 2012). Arrange design elements to minimize errors and hazards. For example, have most frequently used elements as most accessible, and have

hazardous elements hidden or removed. Frequent and important actions should be visible and easily accessible (Fisk et al., 2009). The need for error prevention becomes more critical due to the more rapid pace of events in the mobile environment (Gong & Tarasewich, 2004). Error prevention also needs to take the physical design of mobile devices into account. Smaller device sizes make the proximity of buttons to one another more of a potential problem. Tap targets on touchscreens should be at least 16.5mm diagonally and 11.7mm square (Johnson & Finn, 2017), in colors that stand out (e.g., white on black and black on white). Warning signals should have frequency ranges from 500 to 200 Hz and intensity of at least 60 dB at the ear of the listener (Fisk et al., 2009). Repetitively flash the information for important visual warning messages. For important auditory warning messages, select output systems (e.g., speakers), which emit sounds in the range of 500 to 1000 Hz, and repeat the message until acknowledged. Give preference to text warnings as opposed to symbols and icons that take longer to learn and are less likely to be remembered. Avoid short-duration menu displays because of the slower processing speed of older adults (Fisk et al., 2009). Very simple operations (e.g., power on/off) should not trigger anything potentially harmful (Gong & Tarasewich, 2004). Minimize use of attention-catching techniques, such as flashing and scrolling text and images in the periphery (e.g., advertisements on web pages), because older adults are less able to ignore distractions (Fisk et al., 2009). In addition, they have less effective useful fields of view, which makes them less likely to process events in the periphery in a successful manner similar to that of young adults. This is especially applicable to the pages with important information, such as warnings and errors.

5. **Different modes of use.** Provide different modes (pictorial, verbal, tactile) for redundant presentation of essential information to accommodate different abilities, preferences, and contexts of use (Sanford, 2012). For a design to effectively

communicate necessary information to users with various abilities and preferences regardless of ambient conditions, it should provide as many modes as possible. Use modalities such as sound to convey information where appropriate (Poupyrev et al., 2002). When in the mobile environment, a user has to potentially deal with more distractions than with a desktop computer (Tarasewich, 2003). A mobile application may not be the focal point of the user's current activities (Holland et al., 2001), and a user may not be able to suspend his or her primary task to interact with the mobile device (Gorlenko & Merrick, 2003; Kristoffersen & Ljungberg, 1999). Using alternative interaction modes such as sound can be beneficial (Poupyrev et al., 2002). In addition, provide personalization to allow for variations among users (Gong & Tarasewich, 2004). Allow users to adjust sound volumes and provide instructions regarding how to perform these adjustments. Use frequencies less than 4000 Hz for audio output (Fisk et al., 2009). In addition to sound (Poupyrev et al., 2002), use vibration and light as sensory channels (Fisk et al., 2009). Use low-frequency (25Hz) vibration due to unimpaired sensitivity to this level of frequency with age, and avoid high-frequency vibration (60 Hz and above) (Fisk et al., 2009). Provide parallel visual and auditory language presentation (e.g., speech recognition and closed caption text for public addresses). Prefer upper (e.g., hands) to lower body sites (e.g., legs) for conveying vibratory information. Provide both tactile/haptic and auditory feedback with keypads. In noisy environments and glare situations when auditory and visual output would be difficult to process or would be disruptive to users' performance, prefer tactile output device for simple signaling (e.g., moderate frequency vibration of around 25 Hz) (Fisk et al., 2009).

6. **Easy reversal of actions.** Provide fail-safe features to minimize hazards and errors. Since the user knows that errors can be undone, their anxiety is relieved, and they are encouraged to explore unfamiliar options (Shneiderman, 1986). The units of reversibility may be a single action, a data entry, or a complete group of actions.

Allowing easy reversal of actions may be more difficult for mobile devices because of a lack of available resources and computing power (Satyanarayanan, 1996). If an error is made, the system should be able to detect the error and offer simple, comprehensible mechanisms for handling the error (Shneiderman, 1986). The greater susceptibility of wireless communications to connectivity losses makes tracking of past states more difficult (Kristoffersen & Ljungberg, 1999; Satyanarayanan, 1996). Mobile devices should rely on network connectivity as little as possible (Gong & Tarasewich, 2004).

Interface Structure Guidelines

1. **Same means of use.** Provide the same means of use for people with diverse ranges of abilities, identical whenever possible, and equivalent when not. Ensure provisions for privacy, security, and safety that are equally available to all to avoid segregating or stigmatizing anyone. Participation in all activities, experiences, and application uses should be provided to everyone to eliminate the need for specialized design and signage (Sanford, 2012). Design useful and accessible interfaces for people with diverse ranges of abilities.
2. **Clear and understandable navigation structure.** Provide clear and understandable navigation structure to allow seamless and intuitive use. Allow users to navigate seamlessly (e.g., next, back buttons). Make it clear how to navigate to all main points of the interface from home page, and how to go back to home page from any other page (Ljilja Ruzic & Sanford, 2017). Provide navigation assistance (e.g., help and review buttons, instructions) for how to navigate to specific points in the system (Fisk et al., 2009). This includes navigation to not only the home page, but also any relevant page. Provide specific, clear, and evident instructions for every step of the actions and allow users to disable these instructions (Ljilja Ruzic & Sanford, 2017). Directions should be simplified with

the use of icons. Attentional cues (e.g., highlighting) should be used to support the information search. Make system status clear to users, such as history mode vs. review mode, vs. transfer mode. Provide search history to allow users to know which pages they have visited (Fisk et al., 2009). Have consistent navigation from page to page (Ljilja Ruzic & Sanford, 2017). Provide more than one way to go to different pages while keeping the consistency.

3. **Consistency with expectations.** Provide consistency with expectations to intuition to allow natural, intuitive use. Consistent sequences of actions should be required in similar situations; identical terminology should be used in prompts, menus, and help screens, and consistent commands should be employed throughout. The system functions should match users' expectations (e.g., mental models based on previous experiences should match how the interface system works) (Fisk et al., 2009). As a secondary option, provide training, which enables users to create the appropriate mental models. Always, where possible, promote proper design over the provision of training. Provide consistency across multiple platforms and devices for the same application when users switch between their desktop and mobile devices (Chan et al., 2002), including the "look and feel", names, color schemes, dialog appearances (Gong & Tarasewich, 2004), and standard layouts (Fisk et al., 2009). Create device independent I/O methodologies, and avoid using methods specific to mobile platforms (Isokoski & Raisamo, 2000). Ensure standardized format and keep consistent location of target items within and if possible between the applications (e.g., help information and error messages should always appear at the same location) (Fisk et al., 2009).
4. **Simple and natural use.** Eliminate complexity and arrange information consistent with its importance to allow for natural use (Sanford, 2012). Mobile devices are limited with the amount of information that they can present at one time on their small screens (Gong & Tarasewich, 2004). Reading large amounts of information

from such devices can require large amounts of scrolling and focused concentration. To reduce distraction, interactions, and potential information overload, a better way of presenting information might be through multilevel or hierarchical mechanisms (Brewster, 2002). For example, users may not need or want the entire content of a message, but they may wish to receive a notification that a message is available, along with an indication of its importance. That way, they can make decisions whether or not to stop the primary task in order to access the contents of the message. Avoid scrolling text because it is difficult to process, especially horizontal formats (Fisk et al., 2009). Use a slow scrolling rate if it is necessary to use. Menu structure should match the medium of presentation that the task demands, as well as the users' capabilities. Allow users to focus their attention on one task at a time by aiming for one task on one page (Johnson & Finn, 2017). Users should rely on recognition of function choices instead of memorization of commands (Gong & Tarasewich, 2004). Very little memorization should be required during the performance of tasks (Chan et al., 2002). Minimize clutter: visual (many display items in one location), auditory (many sounds), cognitive (many things to keep in memory), and movement related (many small response items). Avoid use of the picker (Ljilja Ruzic & Sanford, 2017).

5. **Dialogs that yield closure.** Design dialogs to yield closure to allow the satisfaction of accomplishment and completion. Sequences of actions should be organized into groups with a beginning, middle, and end (Shneiderman, 1986). Organize information within natural or consistent groupings (e.g., group related information and have most frequent operations highest on the menu structure) (Fisk et al., 2009). Users should be given the satisfaction of accomplishment and completion, a sense of relief, and an indicator to prepare for the next group of actions, no matter where they are (Shneiderman, 1986) (e.g., after users save any data, provide them with the information that their records have been saved and secured (Ljilja Ruzic & Sanford,

2017)). Indicate clearly where the user currently is at any point of time (Fisk et al., 2009). The sequences of actions should be available and visible in the interface, and the user should not be expected to remember them (Fisk et al., 2009). Provide search history to allow users to know which pages they have visited (e.g., change the color of pages previously visited on a list of pages). Clearly communicate current system status. For example, it needs to be clear which option is active and what the consequences of an action are.

6. **Maximized "legibility" of essential information.** Provide contrast between essential information and its surroundings, differentiate elements in ways that can be described, and allow for compatibility with assistive techniques/devices to increase "legibility" of essential information (Sanford, 2012). Screen characters and targets should be conspicuous and accessible (e.g., icons should be large enough to select easily) (Fisk et al., 2009). Use at least 12-point x-height serif or sans serif fonts (e.g., Arial, Helvetica, Times Roman), preferably 14-point and bigger (L. Kascak, Rebola, et al., 2013b; L. Kascak, Rébola, et al., 2013). Avoid cursive and decorative fonts and use of all uppercase letters since it slows down reading. In mixed-case situations, uppercase text attracts more attention than lowercase ones. Provide at least 50:1 contrast (e.g., black text on white background) (Fisk et al., 2009). Make sure that color discriminations can be made easily by signaling important information using short wavelength (blue-violet-green) contrasts, using black on white or white on black text, avoiding colored and watermarked backgrounds for display of text (Fisk et al., 2009). Provide an easy to use site map with an obvious link to it on every page. Menu structure should match the medium of presentation, the task demands, and the users' capabilities. Frequent and important actions should be visible and easily accessible (Fisk et al., 2009). Provide good structure (e.g., grammar) in spoken and written text (Fisk et al., 2009). Pause after phrases and ends of sentences when speaking. Prefer videoconferencing to

talking on a phone because of using visual cues as a contextual support. Ensure adequate pauses in speech at grammatical boundaries (e.g., after phrases and at the end of the sentence). Match voice characteristics to situation (Fisk et al., 2009). For announcements use male voices rather than female ones. To get attention select female over male voices. Avoid synthesized speech.

7. **Range of literacy and language skills.** Allow for a range of literacy and language skills to accommodate all users. Regardless of user's language skills, knowledge, experience, and literacy level, the way in which design is used should be easy to understand (Sanford, 2012). Choice of vocabulary and content of information is important due to various native languages (Fisk et al., 2009). Technical language used in instructions and help systems might be difficult for older adults, as their educational attainment levels may be lower than that of younger adults. Reading level of text material needs to be kept at grade 10 or below (Fisk et al., 2009).
8. **Internal locus of control.** Let users feel they are in control (output) so provide a choice of alternative solutions for control over decision-making. Users want to be in charge of the system and have the system respond to their actions, rather than feel that the system is controlling them (Shneiderman, 1986). The system should be designed such that users initiate actions rather than respond to them. It should let the user navigate it on their own. The system should not be deterministic; it should provide a choice. For example, to enhance user control provide a choice of linear vs. random access.
9. **Adaptation to users' pace.** Provide adaptable pace to accommodate novice and expert users, different ages, abilities, preferences, situations, and contexts of use. Time constraints need to be taken into account in initial application availability and recovery speed for mobile platforms (Gong & Tarasewich, 2004). When time is critical, waiting a few minutes for an application to start may not be in the user's best interest. Users may need to quickly change or access functions or applications

in different contexts of use (Poupyrev et al., 2002). In these situations, work performed would have to be saved and resumed later without any loss (Poupyrev et al., 2002). Add personalization to accommodate differences among users (Gong & Tarasewich, 2004). Ensure speech rates of 140 wpm or less (Fisk et al., 2009). Avoid compressing and speeding the speech rates because of older adults' slower rate of processing. Have appropriate temporal constraints for carrying out commands (e.g., drop-down and pop-up menu durations should be long enough to carry out the commands). Screen characters and targets should be conspicuous and accessible (e.g., auditory information should be presented at the proper pitch, frequency, and rate). Make system adaptable and flexible to different user levels in a way that it grows with the user's experience and skills (Fisk et al., 2009). As the frequency of use increases, so do the user's desires to reduce the number of interactions and to increase the pace of interaction (Shneiderman, 1986). Abbreviations, function keys, hidden commands, and macro facilities are very helpful to an expert user. The limitation of human information processing in short-term memory requires that displays be kept simple, multiple page displays be consolidated, screen-motion frequency be reduced, and sufficient training time be allotted for codes, mnemonics, and sequences of actions (Shneiderman, 1986).

10. **Multiple and dynamic contexts.** Provide multiple and dynamic contexts to accommodate variations in the environment. Mobile platform users can have a significant number of additional people, objects, and activities vying for their attention outside the application itself (Tarasewich, 2003). In addition, environmental conditions (e.g., brightness, noise levels, weather) can change depending on location, time of day, and season. The usability or appropriateness of an application can change based on these different context factors (Kim, Kim, Lee, Chae, & Choi, 2002). For example, in the presence of strangers, users may feel uncomfortable speaking input aloud, and certain places (e.g., libraries) might

restrict the use of voice input. Small text sizes may work well under office conditions but suddenly become unreadable in bright sunshine or in dimly lit spaces. Thus, allow users to configure output to their needs and preferences (e.g., text size, brightness) (Gong & Tarasewich, 2004). Have the application adapt itself automatically to the user's current environment. Implement context-awareness, self-adapting functionalities, and universal control features, which would work regardless of the context and environment.

11. **Design appealing to all.** The design is appealing to all to enhance usability and marketability. Part of designing an enjoyable user experience is aesthetics (Gong & Tarasewich, 2004). "Aesthetics in use" was defined as dynamic interaction that invokes a positive affective response from the user (Karlsson & Djabri, 2001). In addition, color and its manipulation are important considerations for visual interfaces. Shneiderman (1986) offered color use guidelines for interfaces that can be carried over to mobile devices, although some of the effects of color may be different on smaller screens. Moreover, besides usability and aesthetics, emotion involves a large part of our interaction with objects (Norman, 2004).
12. **Right-, left- or no-handed use.** Provide right or left-handed and single or no-handed access and use to accommodate different abilities, preferences, and contexts of use, such as a significant number of additional people, objects, and activities in users' environments. Due to varying limitations while using mobile applications, such as a significant number of additional people, objects, and activities in users' environments, they could have the ability to use one hand or no hands at all (Gong & Tarasewich, 2004). Therefore, allowing operations with 0, 1, or 2 hands becomes extremely important to the viability of the interface.
13. **Low physical effort.** Use reasonable operating forces, minimize repetitive actions and sustained physical effort to provide ease of use, efficiency, comfort, and

minimize fatigue (Sanford, 2012). Avoid double-clicking (Fisk et al., 2009). Minimize steps (i.e., basic tasks, such as pressing a key) (Fisk et al., 2009).

14. **Variations in hand and grip size.** Accommodate variations in hand and grip size to allow ease of use (Sanford, 2012). Use large keys with clear markings and appropriate inter-key spacing on a keypad (Fisk et al., 2009).
15. **Natural body position.** Maintain natural body position to provide comfort and minimize fatigue. Design should be able to be used from a natural body position to provide physical ease of use and low physical effort (Sanford, 2012).

APPENDIX C. UDMIG V.2.1 DESIGN CRITERIA QUESTIONNAIRE - EXPERT REVIEW AND USABILITY TESTING

The questionnaire rates agreement with the application of each of the UDMIG v.2.1 guideline to the design of the mobile application. This evaluation sheet can help you think about your needs and those of other potential users when interacting with mobile applications.

Design Elements Guidelines					
This application provides…					
1.a. Large enough button size.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
1.b. Good contrast between the background colors against the images and text.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
2.a. Feedback about a confirmation of my activity and a current state.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
2.b. System feedback for my actions, such as a beep when pressing a key or an error message for an invalid input value.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
2.c. Text description for each icon.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
2.d. Obvious feedback (visual, audio, and/or tactile) when a target is selected.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
3. Alternate methods of input and use, such as speech input (e.g., Siri, Voice Control).	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree
4.a. Visible and easily accessible frequent and important actions.	□1 Strongly Disagree	□2 Disagree	□3 Neither	□4 Agree	□5 Strongly Agree

4.b. Text warnings as opposed to symbols and icons.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
4.c. Buttons in colors that stand out, and arranged in linear order.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
5.a. Different modes of feedback, such as sound or vibration.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
5.b. Redundant visual presentation of essential information (e.g., color, icons, and text).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.a. Easy reversal of my actions if I make a mistake, such as "Are you sure you want to send the reports to the selected contacts?", with reversion back to the contacts screen when I press "No".	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.b. The system which can detect the error and offer a prompt message for handling it (e.g., if an entry for weight is skipped, provide a text message "Please enter a target weight").	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
Interface Context Guidelines	
This application provides…	
1.a. The same means of use for all users, by eliminating specialized design and language.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
1.b. One hardware and software application for all users that allows individualized preferences.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
2.a. The same design elements for the navigation from page to page (e.g., Next, Back Home page buttons).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
2.b. Navigation assistance (e.g., menu, instructions) for how to navigate to specific points in the system, which includes navigation to the home page and to any relevant page.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
2.c. Specific, clear, and evident instructions, which can be disabled in Settings and on the instructions page.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
2.d. More than one way to go to different pages while keeping the consistency.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree

3.a. Standardized format and consistent location of target items within (e.g., navigation buttons, and error messages).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
3.b. Identical terminology in prompts, menus, and help screens.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
4.a. **Avoids** use of the picker.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
4.b. **Avoids** scrolling text, especially horizontal formats.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
5.a. Clear indication on the top of the page where the user currently is at any point of time (e.g., diary, reports, games).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
5.b. Related information in a group, and the most frequent operations highest on the page.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
5.c. Clear understanding of which button is active/selected and what are the consequences of my action (e.g., by pressing the selected button and Next button the selected feature page will open).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.a. Large enough and legible fonts whenever possible.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.b. Good structure (e.g., grammar) in written text.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.c. Video conferencing in addition to talking on a phone.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
6.d. **Avoids** cursive and decorative fonts and use of all uppercase letters.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
7.a. Understandable reading level of text material.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
7.b. **Avoids** use of technical language.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree

8. Choice of linear navigation vs. random access.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
9. Personalization to change my skill level from a “novice” to an “expert” user.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
10.a. Configuration of the display settings to my needs and preferences, such as text size, brightness, etc.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
10.b. Configuration of the brightness, noise levels, weather, speech input and output, and similar in settings.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
11. Aesthetically plausible color scheme.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
12. Main navigation buttons of equal importance accessible for me (e.g., Next, Back buttons at the lower left- and right-hand side).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
13.a. Use of a single tap throughout the app instead of double-clicking.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
13.b. Minimized steps (i.e., basic tasks) when possible.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
14.a. Visible spacing between the small buttons.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
14.b Zero or small spacing between the large buttons.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
14.c. The location of the buttons near the center or the bottom of the screen, if possible.	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree
15. Main navigation buttons of equal importance at the bottom of the screen (i.e., Next and Back buttons).	□1 Strongly Disagree □2 Disagree □3 Neither □4 Agree □5 Strongly Agree

APPENDIX D. EXPERT REVIEW – DESIGN CHANGES

Design Feature and Related Characteristic	**Number of Participants, Frequency**	**Design Response**	**Design Changes**
Background, Contrast	N=3 F=30%	Increase contrast	Grey is changed into black to provide more contrast against white and green.
Next and Back buttons, Navigation	N=7 F=70%	No change	No change is made due to the design criteria IC2d. (i.e., Have more than one way to go to different pages while keeping the consistency). Next and Back buttons are a typical of a linear navigation, and will be used in the novice user mode only.
Buttons, Labeling	N=4 F=40%	Change labeling: Education	"Education" is renamed into "Resources".
	N=2 F=20%	Change labeling: Emergency	"Emergency" is renamed into "Emergency Contacts".
	N=1 F=10%	Change labeling: Energized	"Energized" (mood) is changed into "Excited".
	N=2 F=22.22%	Change labeling: Input, Output	"Input" is renamed into "Speech Input", "Touch" into "Touch Input", and "Output" into "Display and Sound".
	N=1 F=10%	Change labeling: Speech	"Speech" is renamed into "Voice".
UI elements, Design	N=3 F=30%	Redesign Profile and Settings buttons	Name of the app, MS Assistant, is taken out of the homepage top navigation bar, and the icons for Profile and Settings are added.
	N=3 F=30%	Redesign header	The color of the icons for the current state (e.g., Diary, Reports, etc.) is changed from black into the color of that function (e.g., Diary icon in green, Reports icon in blue, etc.). In this way, the icon and the header look like the part of the page background and not like the buttons.
	N=2 F=20%	Redesign slider	Numbers on the slider are placed on top of the slider.
Keyboard, spell check	N=1 F=10%	Provide spell check w/keyboard	A spell check is provided within the keyboard.
Keyboard, Page scrolling	N=2 F=20%	Add page scrolling w/keayboard	Page scrolling is added with the use of a keyboard.
Prompt, Content	N=2 F=20%	Redesign prompt	A promt is redesigned to inform about the missing data in a way that allows users to go to the following page without having to fill out all the information (e.g., "Do you want to fill out the missing information?" with Yes that takes them back to the previous page, and No that takes them to the following page).
System, Navigation	N=2 F=20%	Add text to the first instructions page	Text is added bout the navigation and using Next and Back buttons in instructions (on Diary page).
Text, Font size	N=1 F=11.11%	Increase font size	The font size of the MS News articles is increased.
View and Email Report buttons, Layout	N=1 F=10%	Change the layout	View Report button is moved above the Email Report button.
Buttons, Haptic feedback	N=3 F=30%	No change	iPhone 6 does not have the Taptic Engine that allows the vibration while tapping the buttons, which is included in later versions.
Buttons, Single tap	N=1 F=11.11%	No change	No change is made due to the design criteria IC13a (i.e., Use a single tap throughout the app instead of double-clicking).
Button spacing, Layout	N=2 F=20%	Increase spacing	Spacing between the top bar and large buttons (e.g., Manual entry, Week, Month, Year buttons) is increased.

F- frequency (percentage of participants who reported the problem)

APPENDIX E. EXPERT REVIEW AND USABILITY TESTING – STUDY TASKS

1. Enter health and wellness data

Start with entering your mood, symptoms, energy level, daily activity, sleep length and quality, and diet. Enter the following selections for each category:

- Mood: Happy
- Symptoms: Numbness in both arms and legs started at 9:00 a.m. and ended at 3:00 p.m. with severity rated as 2. Difficulty walking started at 10:00 a.m. and ended at 9:00 p.m. with severity rated as 4. You took your medication and you do not want to look at the tips.
- Energy level: Neutral
- Daily activity: Walking for 3 miles started at 9:00 a.m. and ended at 11:00 a.m.
- Sleep length and quality: You went to bed at 10 p.m. and woke up at 7 a.m, and you slept well.
- Diet: For breakfast, you got 1 slice of bread and 2 eggs.

2. Email reports

Email a report with your health data to your healthcare provider Dr. N. Choose mood, symptoms, and sleep during the last month to email as a report.

3. Call MS friend

Call a friend with MS. Let's say you want to call Mike from the list of the friends.

4. Find virtual reality games

Check which virtual reality games are available for you to play.

5. Read the MS news

Check the latest news about MS.

6. Set up the goals

Set up your weight goal.

7. Measure your blood pressure

Manually input your blood pressure on this app (e.g., Systolic: 130, Diastolic: 85, Pulse: 80).

8. Call your healthcare provider

Call your healthcare provider Dr. D.

9. Enter your personal information

Enter your personal information. Please enter all the information you would like to provide if this was your app (MS types: RRMS, PPMS, SPMS, PRMS). What would you enter, and which information would you share with your MS friends?

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10. Customize visuals (text size)

Change the text size to a large text.

REFERENCES

Adamovich, S. V., Merians, A. S., Boian, R., Lewis, J. A., Tremaine, M., Burdea, G. S., … Poizner, H. (2005). A virtual reality—based exercise system for hand rehabilitation post-stroke. *Presence: Teleoperators and Virtual Environments, 14*(2), 161-174.

Agree, E. M. (2014). The potential for technology to enhance independence for those aging with a disability. *Disability and health journal, 7*(1), S33-S39.

Amato, M. P., Ponziani, G., Siracusa, G., & Sorbi, S. (2001). Cognitive dysfunction in early-onset multiple sclerosis: a reappraisal after 10 years. *Archives of neurology, 58*(10), 1602-1606.

Amato, M. P., Portaccio, E., Goretti, B., Zipoli, V., Hakiki, B., Giannini, M., & Razzolini, L. (2010). Cognitive impairment in early stages of multiple sclerosis. *Neurological sciences, 31*(2), 211-214.

Americans With Disabilities Act of 1990, 101-336 C.F.R. (1990).

Anderson, G. F. (2010). *Chronic Care: Making the Case for Ongoing Care*. Princeton, NJ: Robert Wood Johnson Foundation.

Anthony, L., Kim, Y., & Findlater, L. (2013). *Analyzing user-generated youtube videos to understand touchscreen use by people with motor impairments.* Paper presented at the Proceedings of the SIGCHI conference on human factors in computing systems.

Baram, Y., & Miller, A. (2006). Virtual reality cues for improvement of gait in patients with multiple sclerosis. *Neurology, 66*(2), 178-181.

Becker, S. A. (2004). A study of web usability for older adults seeking online health resources. *ACM Transactions on Computer-Human Interaction (TOCHI), 11*(4), 387-406.

Beckerman, H., Kempen, J. C., Knol, D. L., Polman, C. H., Lankhorst, G. J., & de Groot, V. (2013). The first 10 years with multiple sclerosis: the longitudinal course of daily functioning. *Journal of Rehabilitation Medicine, 45*(1), 68-75.

Bederson, B. B., Lee, B., Sherman, R. M., Herrnson, P. S., & Niemi, R. G. (2003). *Electronic voting system usability issues.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Benedetti, M., Piperno, R., Simoncini, L., Bonato, P., Tonini, A., & Giannini, S. (1999). Gait abnormalities in minimally impaired multiple sclerosis patients. *Multiple Sclerosis Journal, 5*(5), 363-368.

Bishop, M., & Frain, M. (2007). Development and initial analysis of multiple sclerosis self-management scale. *International journal of MS care, 9*(2), 35-42.

Bombardier, C. H., Cunniffe, M., Wadhwani, R., Gibbons, L. E., Blake, K. D., & Kraft, G. H. (2008). The efficacy of telephone counseling for health promotion in people with multiple sclerosis: a randomized controlled trial. *Archives of physical medicine and rehabilitation, 89*(10), 1849-1856.

Boulos, M. N., Wheeler, S., Tavares, C., & Jones, R. (2011). How smartphones are changing the face of mobile and participatory healthcare: an overview, with example from eCAALYX. *Biomedical engineering online, 10*(1), 24.

Brewster, S. (2002). Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing, 6*(3), 188-205.

Broeren, J., Rydmark, M., & Sunnerhagen, K. S. (2004). Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study. *Archives of physical medicine and rehabilitation, 85*(8), 1247-1250.

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative research, 6*(1), 97-113.

Camtasia. (1995). Retrieved from https://www.techsmith.com/video-editor.html

Chadwick-Dias, A., McNulty, M., & Tullis, T. (2003). *Web usability and age: how design changes can improve performance.* Paper presented at the ACM SIGCAPH Computers and the Physically Handicapped.

Chan, S. S., Fang, X., Brzezinski, J. R., Zhou, Y., Xu, S., & Lam, J. (2002). Usability for Mobile Commerce Across Multiple Form Factors. *J. Electron. Commerce Res., 3*(3), 187-199.

Charvet, L., Yang, J., Shaw, M., Sherman, K., Xu, J., Haider, L., & Krupp, L. (2016). An Adaptive Computer-Based Cognitive Training Program Improves Cognitive Functioning in Adults with Multiple Sclerosis (MS): Results of a Double-Blind Randomized Active-Placebo-Controlled 12-Week Trial. *Neurology, 86*(16 Supplement), P2-170.

Chen, C. C., Kasven, N., Karpatkin, H. I., & Sylvester, A. (2007). Hand strength and perceived manual ability among patients with multiple sclerosis. *Archives of physical medicine and rehabilitation, 88*(6), 794-797.

Chiaravalloti, N. D., & DeLuca, J. (2008). Cognitive impairment in multiple sclerosis. *The Lancet Neurology, 7*(12), 1139-1151.

Chruzander, C. (2014). *A 10-year follow-up of people with multiple sclerosis-aspects of disability and health, use of and satisfaction with care, and feasibility of cognitive behavioural therapy*: Inst för neurobiologi, vårdvetenskap och samhälle/Dept of Neurobiology, Care Sciences and Society.

Chruzander, C., Ytterberg, C., Gottberg, K., Einarsson, U., Holmqvist, L. W., & Johansson, S. (2014). A 10-year follow-up of a population-based study of people with multiple sclerosis in Stockholm, Sweden: changes in health-related quality of life and the value of different factors in predicting health-related quality of life. *Journal of the neurological sciences, 339*(1-2), 57-63.

CogniFit. (2016). Retrieved from https://www.cognifit.com/

Colby, S. L., & Ortman, J. M. (2017). Projections of the size and composition of the US population: 2014 to 2060. Population estimates and projections.

Connell, B. R., Jones, M., Mace, R., Mueller, J., Mullick, A., Ostroff, E., & Vanderheiden, G. (1997). Universal Design Principles. Retrieved from https://www.ncsu.edu/ncsu/design/cud/about_ud/udprinciplestext.htm

Corrigan, J. M., & Adams, K. (2003). *Priority areas for national action: transforming health care quality*. Washington, DC: National Academies Press.

Crosbie, J., Lennon, S., McNeill, M., & McDonough, S. (2006). Virtual reality in the rehabilitation of the upper limb after stroke: the user's perspective. *CyberPsychology & Behavior, 9*(2), 137-141.

Czaja, S. J., & Sharit, J. (2012). *Designing training and instructional programs for older adults*. Boca Raton, FL: CRC Press.

Darkins, A. W., & Cary, M. A. (2000). *Telemedicine and telehealth: Principles, policies, performances and pitfalls*. New York, NY: Springer Publishing Company, Inc.

De Giglio, L., Tona, F., De Luca, F., Petsas, N., Prosperini, L., Bianchi, V., … Pantano, P. (2016). Multiple sclerosis: Changes in thalamic resting-state functional connectivity induced by a home-based cognitive rehabilitation program. *Radiology, 280*(1), 202-211.

De Winter, J. C., & Dodou, D. (2010). Five-point Likert items: t-test versus Mann-Whitney-Wilcoxon. *Practical Assessment, Research & Evaluation, 15*(11), 2.

Devezas, T., Mashapa, J., Giesteira, B., Greunen, D., & Carreira, C. (2014). *ICT4D HCI Guidelines: A study for Developing Countries.* Paper presented at the Proceedings of the 8th International Development Informatics Association Conference (2014).

DiLorenzo, T. (2011). Aging with multiple sclerosis. *Clinical Bulletin, Information for Health Professionals*, 1-9.

Donoghue, D., & Stokes, E. K. (2009). How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people. *Journal of Rehabilitation Medicine, 41*(5), 343-346.

Dvorkin, A. Y., Shahar, M., & Weiss, P. L. (2006). Reaching within video-capture virtual reality: using virtual reality as a motor control paradigm. *CyberPsychology & Behavior, 9*(2), 133-136.

Einarsson, U., Gottberg, K., Fredrikson, S., Von Koch, L., & Holmqvist, L. W. (2006). Activities of daily living and social activities in people with multiple sclerosis in Stockholm County. *Clinical Rehabilitation, 20*(6), 543-551.

Einarsson, U., Gottberg, K., Von Koch, L., Fredrikson, S., Ytterberg, C., Jin, Y., … Holmqvist, L. W. (2006). Cognitive and motor function in people with multiple sclerosis in Stockholm County. *Multiple Sclerosis Journal, 12*(3), 340-353.

Esculier, J.-F., Vaudrin, J., Bériault, P., Gagnon, K., & Tremblay, L. E. (2012). Home-based balance training programme using Wii Fit with balance board for Parkinson's disease: a pilot study. *Journal of Rehabilitation Medicine, 44*(2), 144-150.

Falls Among Older Adults: An Overview. (2013). *Centers for Disease Control and Prevention.* Retrieved from: http://www.cdc.gov/homeandrecreationalsafety/falls/adultfalls.html

Fan, C., Forlizzi, J., & Dey, A. (2012). *Considerations for technology that support physical activity by older adults.* Paper presented at the Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility.

Faulkner, L. (2003). Beyond the five-user assumption: Benefits of increased sample sizes in usability testing. *Behavior Research Methods, Instruments, & Computers, 35*(3), 379-383.

Finlayson, M. (2002). Health and social profile of older adults with MS: Findings from three studies. *International Journal of MS Care, 4*(3), 139-151.

Finlayson, M., Preissner, K., Cho, C., & Plow, M. (2011). Randomized trial of a teleconference-delivered fatigue management program for people with multiple sclerosis. *Multiple Sclerosis Journal, 17*(9), 1130-1140.

Finlayson, M., Van Denend, T., & Hudson, E. (2004). Aging with multiple sclerosis. *Journal of Neuroscience Nursing, 36*(5), 245.

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). *Designing for older adults: Principles and creative human factors approaches.* Boca Raton, FL: CRC Press.

Fjeldsoe, B. S., Marshall, A. L., & Miller, Y. D. (2009). Behavior change interventions delivered by mobile telephone short-message service. *American journal of preventive medicine, 36*(2), 165-173.
Fleming, W. E., & Pollak, C. P. (2005). *Sleep disorders in multiple sclerosis.* Paper presented at the Seminars in neurology.
Fraser, R., Ehde, D., Amtmann, D., Verrall, A., Johnson, K. L., Johnson, E., & Kraft, G. H. (2013). Self-management for people with multiple sclerosis: report from the first international consensus conference, November 15, 2010. *International journal of MS care, 15*(2), 99-106.
Fung, J., Malouin, F., McFadyen, B., Comeau, F., Lamontagne, A., Chapdelaine, S., … Richards, C. (2004). *Locomotor rehabilitation in a complex virtual environment.* Paper presented at the Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE.
Galletta, A. (2013). *Mastering the semi-structured interview and beyond: From research design to analysis and publication*. New York, NY: NYU press.
Glanz, B. I., Healy, B. C., Hviid, L. E., Chitnis, T., & Weiner, H. L. (2012). Cognitive deterioration in patients with early multiple sclerosis: a 5-year study. *J Neurol Neurosurg Psychiatry, 83*(1), 38-43.
Glueckauf, R. L., & Noël, L. T. (2011). Telehealth and family caregiving: Developments in research, education, policy, and practice. In *Education and support programs for caregivers* (pp. 85-105). Springer.
Gong, J., & Tarasewich, P. (2004). *Guidelines for handheld mobile device interface design.* Paper presented at the Proceedings of DSI 2004 Annual Meeting.
Gorlenko, L., & Merrick, R. (2003). No wires attached: Usability challenges in the connected mobile world. *IBM Systems Journal, 42*(4), 639-651.
Gorniak, S. L., Plow, M., McDaniel, C., & Alberts, J. L. (2014). Impaired object handling during bimanual task performance in multiple sclerosis. *Multiple sclerosis international*.
Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational evaluation and policy analysis, 11*(3), 255-274.
Gulick, E. E. (1998). Symptom and activities of daily living trajectory in multiple sclerosis: a 10-year study. *Nursing Research, 47*(3), 137-146.
Haase, R., Schultheiss, T., Kempcke, R., Thomas, K., & Ziemssen, T. (2012). Use and acceptance of electronic communication by patients with multiple sclerosis: a multicenter questionnaire study. *Journal of medical Internet research, 14*(5), e135.
Hansen, K., Schüssel, K., Kieble, M., Werning, J., Schulz, M., Friis, R., … Kugler, J. (2015). Adherence to disease modifying drugs among patients with multiple sclerosis in Germany: a retrospective cohort study. *PloS one, 10*(7), e0133279.
Harrington, C. N., Mitzner, T. L., & Rogers, W. A. (2015). Understanding the role of technology for meeting the support needs of older adults in the USA with functional limitations. *Gerontechnology*, *14*(1), 21-31.
Harris, J. (2010). The use, role and application of advanced technology in the lives of disabled people in the UK. *Disability & Society, 25*(4), 427-439.
Health. (2017). Retrieved from https://www.apple.com/ios/health/

Holland, S., Morse, D. R., & Gedenryd, H. (2001). Audio GPS: spatial audio in a minimal attention interface. *Environment, 1*, 3.

Holman, H., & Lorig, K. (2004). Patient self-management: a key to effectiveness and efficiency in care of chronic disease. *Public health reports, 119*(3), 239-243.

Holzinger, A., Searle, G., & Nischelwitzer, A. (2007). *On some aspects of improving mobile applications for the elderly.* Paper presented at the International Conference on Universal Access in Human-Computer Interaction.

iHealth. (2012). Nov 03, 2016. Retrieved from https://ihealthlabs.com/

Imrie, R. (2012). Universalism, universal design and equitable access to the built environment. *Disability and rehabilitation, 34*(10), 873-882.

Isokoski, P., & Raisamo, R. (2000). *Device independent text input: A rationale and an example.* Paper presented at the Proceedings of the working conference on Advanced visual interfaces.

Iwarsson, S. (2005). A long-term perspective on person–environment fit and ADL dependence among older Swedish adults. *The Gerontologist, 45*(3), 327-336.

Janssens, A. C., Van Doorn, P., De Boer, J., Kalkers, N., van der Meché, F. G., Passchier, J., & Hintzen, R. (2003). Anxiety and depression influence the relation between disability status and quality of life in multiple sclerosis. *Multiple Sclerosis Journal, 9*(4), 397-403.

Jette, A. M., & Field, M. J. (2007). *The future of disability in America*. Washington, DC: The National Academies Press.

Johansson, S., Ytterberg, C., Claesson, I. M., Lindberg, J., Hillert, J., Andersson, M., … von Koch, L. (2007). High concurrent presence of disability in multiple sclerosis. *Journal of Neurology, 254*(6), 767.

Johnson, J., & Finn, K. (2017). *Designing User Interfaces for an Aging Population: Towards Universal Design*. Cambridge, MA, USA: Morgan Kaufmann.

Karlsson, P., & Djabri, F. (2001). *Analogue styled user interfaces: An exemplified set of principles intended to improve aesthetic qualities in use.* Paper presented at the Proceedings of Mobile HCI 2001: Third International Workshop on Human-Computer Interaction with Mobile Devices.

Kascak, L., Rebola, C. B., Braunstein, R., & Sanford, J. (2013a). *Mobile Application Concept Development for Remote Patient Monitoring.* Paper presented at the Healthcare Informatics (ICHI), 2013 IEEE International Conference on.

Kascak, L., Rebola, C. B., Braunstein, R., & Sanford, J. A. (2013b). Icon design to improve communication of health information to older adults. *Communication Design Quarterly Review, 2*(1), 6-32.

Kascak, L., Rébola, C. B., Braunstein, R., & Sanford, J. A. (2013). *Icon design for user interface of remote patient monitoring mobile devices.* Paper presented at the Proceedings of the 31st ACM international conference on Design of communication.

Kascak, L., Rébola, C. B., & Sanford, J. (2014). *Integrating Universal Design (UD) Principles and Mobile Design Guidelines to Improve Design of Mobile Health Applications for Older Adults.* Paper presented at the Healthcare Informatics (ICHI), 2014 IEEE International Conference on.

Kascak, L. R., Liu, E. Y., & Sanford, J. A. (2015). Universal Design (UD) Guidelines for Interactive Mobile Voting Interfaces for Older Adults. In *Universal Access in*

Human-Computer Interaction. Access to the Human Environment and Culture (pp. 215-225), Springer, Cham.

Khan, F., & Pallant, J. F. (2007). Use of International Classification of Functioning, Disability and Health (ICF) to describe patient-reported disability in multiple sclerosis and identification of relevant environmental factors. *Journal of Rehabilitation Medicine, 39*(1), 63-70.

Kim, H., Kim, J., Lee, Y., Chae, M., & Choi, Y. (2002). *An empirical study of the use contexts and usability problems in mobile Internet.* Paper presented at the System Sciences, 2002. HICSS. Proceedings of the 35th Annual Hawaii International Conference on.

Kitzinger, J. (1994). The methodology of focus groups: the importance of interaction between research participants. *Sociology of health & illness, 16*(1), 103-121.

Knaster, E. S., Yorkston, K. M., Johnson, K., McMullen, K. A., & Ehde, D. M. (2011). Perspectives on self-management in multiple sclerosis: a focus group study. *International journal of MS care, 13*(3), 146-152.

Köpke, S., Kasper, J., Mühlhauser, I., Nübling, M., & Heesen, C. (2009). Patient education program to enhance decision autonomy in multiple sclerosis relapse management: a randomized-controlled trial. *Multiple Sclerosis Journal, 15*(1), 96-104.

Krishnan, V., De Freitas, P. B., & Jaric, S. (2008). Impaired object manipulation in mildly involved individuals with multiple sclerosis. *Motor Control, 12*(1), 3-20.

Kristoffersen, S., & Ljungberg, F. (1999). *"Making place" to make IT work: empirical explorations of HCI for mobile CSCW.* Paper presented at the Proceedings of the international ACM SIGGROUP conference on Supporting group work.

Krueger, R. A. (2014). *Focus groups: A practical guide for applied research*. Thousand Oaks, CA: Sage publications.

Langdon, D., Amato, M., Boringa, J., Brochet, B., Foley, F., Fredrikson, S., … Reder, A. T. (2012). Recommendations for a brief international cognitive assessment for multiple sclerosis (BICAMS). *Multiple Sclerosis Journal, 18*(6), 891-898.

Lange, B., Requejo, P., Flynn, S. M., Rizzo, A., Valero-Cuevas, F., Baker, L., & Winstein, C. (2010). The potential of virtual reality and gaming to assist successful aging with disability. *Physical medicine and rehabilitation clinics of North America, 21*(2), 339-356.

Law, C. M., Yi, J. S., Choi, Y. S., & Jacko, J. A. (2008). A systematic examination of universal design resources: part 1, heuristic evaluation. *Universal Access in the Information Society, 7*(1-2), 31-54.

Lawton, M. P., & Nahemow, L. (1973). Ecology and the aging process. In C. Eisdorfer & M. P. Lawton (Eds.), *The psychology of adult development and aging* (pp. 619-674). Washington, DC, US: American Psychological Association.

Lee, G. H. (2016). Effects of Virtual Reality Exercise Program on Balance, Emotion and Quality of Life in Patients with Cognitive Decline. *The Journal of Korean Physical Therapy, 28*(6), 355-363.

Lee, S. T., Liu, Y. E., Ruzic, L., & Sanford, J. (2016). *Universal design ballot interfaces on voting performance and satisfaction of voters with and without vision loss.* Paper presented at the Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.

Leonardi, C., Mennecozzi, C., Not, E., Pianesi, F., & Zancanaro, M. (2008). Designing a familiar technology for elderly people. *Gerontechnology, 7*(2), 151.

Lewis, C., & Norman, D. A. (1995). Designing for error. In *Readings in Human–Computer Interaction.* Elsevier, 686-697.

Lorig, K. R., & Holman, H. R. (2003). Self-management education: history, definition, outcomes, and mechanisms. *Annals of behavioral medicine, 26*(1), 1-7.

Lumosity. (2016). Retrieved from https://www.lumosity.com/

Mace, R. (1988). Universal design: housing for the lifespan of all people. *US Department of Housing and Urban Affairs.* Washington DC, US.

Mace, R. (1997). What is universal design. *The Center for Universal Design at North Carolina State University.* Retrieved November 19, 2004.

Månsson Lexell, E., Iwarsson, S., & Lexell, J. (2006). The complexity of daily occupations in multiple sclerosis. *Scandinavian journal of occupational therapy, 13*(4), 241-248.

Marwaha, R., Hall, S. J., Knight, C. A., & Jaric, S. (2006). Load and grip force coordination in static bimanual manipulation tasks in multiple sclerosis. *Motor Control, 10*(2), 160-177.

Meiselwitz, G., Wentz, B., & Lazar, J. (2010). Universal usability: Past, present, and future. *Foundations and Trends®* in Human–Computer Interaction, 3(4), 213-333.

Mendiola, M. F., Kalnicki, M., & Lindenauer, S. (2015). Valuable features in mobile health apps for patients and consumers: content analysis of apps and user ratings. *JMIR mHealth and uHealth, 3*(2).

Merians, A. S., Jack, D., Boian, R., Tremaine, M., Burdea, G. C., Adamovich, S. V., & Poizner, H. (2002). Virtual reality–augmented rehabilitation for patients following stroke. *Physical therapy, 82*(9), 898-915.

Merians, A. S., Tunik, E., & Adamovich, S. V. (2009). Virtual reality to maximize function for hand and arm rehabilitation: exploration of neural mechanisms. *Studies in health technology and informatics, 145*, 109.

Minden, S. L., Frankel, D., Hadden, L. S., Srinath, K., & Perloff, J. N. (2004). Disability in elderly people with multiple sclerosis: an analysis of baseline data from the Sonya Slifka Longitudinal Multiple Sclerosis Study. *NeuroRehabilitation, 19*(1), 55-67.

Mohr, D. C., Hart, S. L., Julian, L., Catledge, C., Honos-Webb, L., Vella, L., & Tasch, E. T. (2005). Telephone-administered psychotherapy for depression. *Archives of General Psychiatry, 62*(9), 1007-1014.

Mohr, D. C., Likosky, W., Bertagnolli, A., Goodkin, D. E., Van Der Wende, J., Dwyer, P., & Dick, L. P. (2000). Telephone-administered cognitive–behavioral therapy for the treatment of depressive symptoms in multiple sclerosis. *Journal of consulting and clinical psychology, 68*(2), 356.

Morgan, D. L. (1996a). Focus groups. *Annual review of sociology, 22*(1), 129-152.

Morgan, D. L. (1996b). Focus groups as qualitative research. *SAGE Research Methods*, *16*, 2-18. Sage publications.

Morrell, R. W. (2001). *Older adults, health information, and the World Wide Web*. Mahwah, NJ: Lawrence Erlbaum Associates.

Moses Jr, H., Picone, M., & Smith, V. (2008). *Clinician's primer on multiple sclerosis: An indepth overview*: Teva Neuroscience, Consensus Medical Communications, Englwood, CO.

Mr. Tappy. (2018). Retrieved from https://www.mrtappy.com/

MS Buddy. (2016). Retrieved from http://www.healthline.com/health/multiple-sclerosis/ms-buddy

MS Journal. (2014). Retrieved Oct 27, 2014 from http://tensai-solutions.com/app/ms-journal/

MS self – Multiple Sclerosis (MS) App. (2015). Retrieved Oct 27, 2014 from http://www.moveoverms.org/multiple-sclerosis-app-ms-self/

Multiple Sclerosis Attack App. (2014). Retrieved Oct 27, 2014 from https://itunes.apple.com/us/app/multiple-sclerosis-attack/id883546897?mt=8

My MS Conversations™. (2015). Retrieved Oct 27, 2014 from https://play.google.com/store/apps/details?id=com.syandus.ms_patiented_01&hl=en

My MS Manager ™. (2012). Retrieved Oct 27, 2014 from http://mymsaa.org/manage-your-ms/mobile/

My Multiple Sclerosis Diary. (2015). Retrieved Oct 27, 2014 from https://play.google.com/store/apps/details?id=com.appxient.mymsdiary&hl=en

MyBrainGames. (2016). Retrieved Oct 27, 2014 from http://www.multiplesclerosis.com/mybraingames/game_iframe.html

MySidekick for MS. (2012). Retrieved Oct 27, 2014 from https://www.abovems.com/

Naar-King, S., Ellis, D. A., Frey, M. A., & Ondersma, M. L. (2003). *Assessing children's well-being: A handbook of measures*. New York, NY: Routledge.

Nielsen, J. Quantitative Studies: How Many Users to Test, 2006. *URL {http://www. nngroup. com/articles/quantitative-studies-how-many-users/}*.

Nilsagård, Y., Gunnarsson, L.-G., & Denison, E. (2007). Self-perceived limitations of gait in persons with multiple sclerosis. *Advances in physiotherapy, 9*(3), 136-143.

Norman, D. A. (2004). *Emotional design: Why we love (or hate) everyday things*: Basic books.

Organization, W. H. (2001). *International classification of functioning, disability and health: ICF*. Geneva, Switzarlend: World Health Organization.

Ortiz-Gutiérrez, R., Cano-de-la-Cuerda, R., Galán-del-Río, F., Alguacil-Diego, I. M., Palacios-Ceña, D., & Miangolarra-Page, J. C. (2013). A telerehabilitation program improves postural control in multiple sclerosis patients: a Spanish preliminary study. *International journal of environmental research and public health, 10*(11), 5697-5710.

Parhi, P., Karlson, A. K., & Bederson, B. B. (2006). *Target size study for one-handed thumb use on small touchscreen devices.* Paper presented at the Proceedings of the 8th conference on Human-computer interaction with mobile devices and services.

Ploughman, M., Austin, M. W., Murdoch, M., Kearney, A., Fisk, J. D., Godwin, M., & Stefanelli, M. (2012). Factors influencing healthy aging with multiple sclerosis: a qualitative study. *Disability and rehabilitation, 34*(1), 26-33.

Poupyrev, I., Maruyama, S., & Rekimoto, J. (2002). *Ambient touch: designing tactile interfaces for handheld devices.* Paper presented at the Proceedings of the 15th annual ACM symposium on User interface software and technology.

Rae-Grant, A. D., Turner, A. P., Sloan, A., Miller, D., Hunziker, J., & Haselkorn, J. K. (2011). Self-management in neurological disorders: systematic review of the literature and potential interventions in multiple sclerosis care. *Journal of rehabilitation research and development, 48*(9), 1087.

Reason, J. (2000). Human error: models and management. *Bmj, 320*(7237), 768-770.

Rivaetal, G. (1998). Virtual Reality in Paraplegia: Avr-Enhanced Orthopaedic Appliance for Walking and Rehabilitation. *Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist interaction, 58*, 209.

Rompani, P., & Dua, T. (2008). *Atlas: Multiple sclerosis resources in the world 2008*. Geneva, Switzerland: WHO Press, World Health Organization.

Rubin, J., & Chisnell, D. (2008). *Handbook of usability testing: how to plan, design, and conduct effective tests*. Indianapolis, IN: John Wiley & Sons.

Ruptash, S. (2013). Universal Design through Passion, Knowledge and Regulations? *Trends in Universal Design*, *24*.

Ruzic Kascak, L., Liu, E. Y., & Sanford, J. A. (2015). Universal Design (UD) Guidelines for Interactive Mobile Voting Interfaces for Older Adults. In *Universal Access in Human-Computer Interaction. Access to the Human Environment and Culture* (pp. 215-225), Springer.

Ruzic Kascak, L., Rebola, C. B., & Sanford, J. A. (2014). *Integrating Universal Design (UD) principles and mobile design guidelines to improve design of mobile health applications for older adults.* Paper presented at the Healthcare Informatics (ICHI), 2014 IEEE International Conference on Healthcare Informatics.

Ruzic, L., Harrington, C. N., & Sanford, J. A. (2017). *Design and Evaluation of Mobile Interfaces for an Aging Population.* Paper presented at the The Tenth International Conference on Advances in Computer-Human Interactions (ACHI 2017) IARIA, Nice, France.

Ruzic, L., Lee, S. T., Liu, E. Y., & Sanford, J. A. (2016). Development of Universal Design Mobile Interface Guidelines (UDMIG) for Aging Population. In *Universal Access in Human-Computer Interaction. Access to the Human Environment and Culture* (pp. 98-108). Springer, Cham.

Ruzic, L., & Sanford, J. A. (2017). Usability of Mobile Consumer Applications for Individuals Aging with Multiple Sclerosis. In *Universal Access in Human-Computer Interaction. Access to the Human Environment and Culture* (pp. 258-276). Springer, Cham.

Ruzic, L., & Sanford, J. A. (2018). Needs Assessment—mHealth Applications for People Aging with Multiple Sclerosis. *Journal of Healthcare Informatics Research*, 1-28.

Ryan, P., & Sawin, K. J. (2009). The individual and family self-management theory: Background and perspectives on context, process, and outcomes. *Nursing Outlook, 57*(4), 217-225. e216.

Sabate, E. (2003). *Adherence to long-term therapies: evidence for action*. Geneva, Switzerland: World Health Organization.

Sanchez, R. J., Liu, J., Rao, S., Shah, P., Smith, R., Rahman, T., … Reinkensmeyer, D. J. (2006). Automating arm movement training following severe stroke: functional exercises with quantitative feedback in a gravity-reduced environment. *IEEE Transactions on neural systems and rehabilitation engineering, 14*(3), 378-389.

Sanford, J. A. (2012). *Universal Design as a Rehabilitation Strategy: Design for the Ages*. New York, NY: Springer Publishing Company.

Sanford, J. A., & Gonzalez, E. T. (2016). RERC TechSAge: Making a Difference to the Lives of Older Adults with Disability Through Design and Technology, In: Zhou J., Salvendy G. (eds) *Human Aspects of IT for the Aged Population. Design for Aging.* ITAP 2016. Lecture Notes in Computer Science, vol 9754. Springer, Cham.

Santo, K., Richtering, S. S., Chalmers, J., Thiagalingam, A., Chow, C. K., & Redfern, J. (2016). Mobile phone apps to improve medication adherence: a systematic stepwise process to identify high-quality apps. *JMIR mHealth and uHealth, 4*(4).

Satyanarayanan, M. (1996). *Fundamental challenges in mobile computing.* Paper presented at the Proceedings of the fifteenth annual ACM symposium on Principles of distributed computing.

Sauro, J. (2011). *A practical guide to the system usability scale: Background, benchmarks & best practices*. Measuring Usability LLC.

Schoene, D., Lord, S. R., Delbaere, K., Severino, C., Davies, T. A., & Smith, S. T. (2013). A randomized controlled pilot study of home-based step training in older people using videogame technology. *PloS one, 8*(3), e57734.

ScreenFlow. (2018). Retrieved from https://www.telestream.net/screenflow/overview.htm

Sheets, D. (2005). Aging with disabilities: ageism and more. *Generations, 29*(3), 37-41.

Shneiderman, B. (1986). *Designing the user interface: strategies for effective human-computer interaction*. Boston, MA: Addison-Wesley Reading Publ. Co.

Shneiderman, B. (2000). Universal usability. *Communications of the ACM, 43*(5), 84-91.

Shneiderman, B. (2003). *Promoting universal usability with multi-layer interface design.* Paper presented at the ACM SIGCAPH Computers and the Physically Handicapped.

Shneiderman, B. (2004). Designing for fun: how can we design user interfaces to be more fun? *Interactions, 11*(5), 48-50.

Shneiderman, B. (2016). *The new ABCs of research: Achieving breakthrough collaborations*. Oxford University Press.

Shneiderman, B., & Plaisant, C. (1987). Designing the user interface: Strategies for effective human-computer interaction. Addison-Wesley. 672p.

Shneiderman, B., & Plaisant, C. (2010). *Designing the User Interface: Strategies for Effective Human-Computer Interaction: Fifth Edition* (Fifth Edition ed.). Reading, MA: Addison-Wesley Publ. Co.

Six, J. M. (2009). Usability Testing Versus Expert Reviews. Retrieved from https://www.uxmatters.com/mt/archives/2009/10/usability-testing-versus-expert-reviews.php

Skype for iPhone. (2017). Retrieved from https://itunes.apple.com/us/app/skype-for-iphone/id304878510?mt=8

Statistics, B. L. (2012). Persons with a Disability: Labor Force Characteristics–2011. Washington, DC.

Stern, M. (2005). Aging with multiple sclerosis. *Physical medicine and rehabilitation clinics of North America, 16*(1), 219-234.

Stern, M., Sorkin, L., Milton, K., & Sperber, K. (2010). Aging with multiple sclerosis. *Physical medicine and rehabilitation clinics of North America, 21*(2), 403-417.

Stewart, D. W., & Shamdasani, P. N. (2014). *Focus groups: Theory and practice* (Vol. 20). Thousand Oaks, CA: Sage publications.

Stewart, J. C., Yeh, S.-C., Jung, Y., Yoon, H., Whitford, M., Chen, S.-Y., … Winstein, C. J. (2007). Intervention to enhance skilled arm and hand movements after stroke: A feasibility study using a new virtual reality system. *Journal of neuroengineering and rehabilitation, 4*(1), 1-6.

Strecher, V. J., Seijts, G. H., Kok, G. J., Latham, G. P., Glasgow, R., DeVellis, B., … Bulger, D. W. (1995). Goal setting as a strategy for health behavior change. *Health education quarterly, 22*(2), 190-200.

Stuifbergen, A. K., Becker, H., Blozis, S., Timmerman, G., & Kullberg, V. (2003). A randomized clinical trial of a wellness intervention for women with multiple sclerosis. *Archives of physical medicine and rehabilitation, 84*(4), 467-476.

Sy, D. (2009). Usability Over Time: Longitudinal Research Studies. Retrieved from http://dux.typepad.com/dux/2009/05/usability-over-time-longitudinal-research-studies.html

SymTrac. (2014). Retrieved April 2014 from http://www.symtrac.com/

Tarasewich, P. (2003). Designing mobile commerce applications. *Communications of the ACM, 46*(12), 57-60.

Teng, J. (2015). *The effectiveness of video tutorial and preview on self-efficacy, task performance and learning: an experimental study conducted at a middle school in Shanghai, China.* University of Twente.

Thakkar, J., Kurup, R., Laba, T.-L., Santo, K., Thiagalingam, A., Rodgers, A., … Chow, C. K. (2016). Mobile telephone text messaging for medication adherence in chronic disease: a meta-analysis. *JAMA internal medicine, 176*(3), 340-349.

Tobias, J. (2003). Universal design: Is it really about design. *Information Technology and Disabilities, 9*(2).

Van Biljon, J., & Renaud, K. (2016). *Validating mobile phone design guidelines: focusing on the elderly in a developing country.* Paper presented at the Proceedings of the Annual Conference of the South African Institute of Computer Scientists and Information Technologists.

Wagner, E. H. (1998). Chronic disease management: what will it take to improve care for chronic illness? *Effective clinical practice: ECP, 1*(1), 2-4.

Wagner, E. H., Austin, B. T., Davis, C., Hindmarsh, M., Schaefer, J., & Bonomi, A. (2001). Improving chronic illness care: translating evidence into action. *Health Affairs, 20*(6), 64-78.

Weather Underground: Forecast. (2017). Retrieved from https://itunes.apple.com/us/app/weather-underground-forecast/id486154808?mt=8&ign-mpt=uo%3D4

WebAIM. (2016). Web Content Accessibility Guidelines 2.0.

Yamout, B., Issa, Z., Herlopian, A., El Bejjani, M., Khalifa, A., Ghadieh, A., & Habib, R. (2013). Predictors of quality of life among multiple sclerosis patients: a comprehensive analysis. *European journal of neurology, 20*(5), 756-764.

Ytterberg, C., Johansson, S., Andersson, M., Holmqvist, L. W., & von Koch, L. (2008). Variations in functioning and disability in multiple sclerosis. *Journal of neurology, 255*(7), 967-973.

Yuen, H. K., Holthaus, K., Kamen, D. L., Sword, D., & Breland, H. L. (2011). Using Wii Fit to reduce fatigue among African American women with systemic lupus erythematosus: a pilot study. *Lupus, 20*(12), 1293-1299.

Zajicek, M. (2001). *Interface design for older adults.* Paper presented at the Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly.

Zulman, D. M., Jenchura, E. C., Cohen, D. M., Lewis, E. T., Houston, T. K., & Asch, S. M. (2015). How can eHealth technology address challenges related to multimorbidity? Perspectives from patients with multiple chronic conditions. *Journal of general internal medicine, 30*(8), 1063-1070.